HOW IT IS DONE

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...WILLIAMS

Author... Modern Invention,"

...etc., etc.

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How It is Done

or,

VICTORIES OF THE ENGINEER

Describing in simple language how great Engineering
Achievements in all parts of the world
have been accomplished

By

ARCHIBALD WILLIAMS

Author of "The Romance of Modern Invention,"
"How It is Made,"
"How It Works,"
etc., etc.

New York
THOMAS NELSON AND SONS
37 East 18th Street

AUTHOR'S NOTE.

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I am under special obligations to my draughtsman, Mr. H. Ludar Lee, and to Mr. E. H. Fitchew, for the preparation of many of the diagrams included in this book.

HOW IT IS DONE

Chapter XIX.—TUNNELS AND TUNNELLING.

Chapter XX.—SUBMARINE TUNNELS.

Chapter XXI.—MINING AND MINES.

HOW IT IS DONE

OR

VICTORIES OF THE ENGINEER

Chapter I.

RAILROAD ENGINEERING.

The significance of the railroad—What the railroad engineer has to do—Preliminary operations—The *reconnaissance*—"Development"—Helical tunnels—Preliminary surveys—Levelling—Contours—The surveyor's life—Location survey—Ranging curves—The theodolite—Several methods of ranging described—Road construction—Record tracklaying—Cuttings and embankments—Blasting rock—A trestle through a lake—Snowsheds—Laying the track—Preparing the ties—Standard rails—Driving the last spike on the Canadian Pacific Railway—Rack railways—Jungfrau Railway—Pike's Peak Railway.

PROBABLY the first kind of work that one thinks of in connection with the word "engineering" is that of railroad building. That this should be so is due to the fact that railroad engineering is so extremely comprehensive. For the railroad the biggest bridges are built; for it the longest tunnels are driven through mountains and under rivers; for it huge gaps are blasted through the rock, and mighty embankments thrown across the valley. Then,

again, the vastness of railroad enterprises grips the imagination. In America folk said, "We want a quick way across this continent to the Pacific," and the Rockies were pierced over and over again. Russia sighed for a port in Pacific waters, and lo! the Trans-Siberian, trailing its 5,000 miles through steppes, swamps, forests, and mountains. To Britons came a vision of a steel track from Egypt to the Cape; and the engineers have pushed north and south till the vision has almost become fact. More, they have thrown out a great branch from the Victoria Nyanza to Mombasa on the east, and on the west another great feeder to Lobito Bay. In South America the Andes will soon be conquered by the Trans-Andine Railway. Before many years have passed trains will travel from Berlin to Bagdad; possibly from St. Petersburg to Calcutta. The railroad men have tamed the Jungfrau and scaled Pike's Peak, have pushed up the Himalayas to Darjeeling, have taken the rails three miles into the air in Peru. Snow and ice do not deter them—witness the White Pass Railway threading storm-swept defiles once almost impassable to man.

But if we attempted anything like a full list of wonderful railroad feats we should fill up the space

allotted to this chapter. Everybody who has read or travelled knows well enough that the railroad engineer has no acquaintance with the word "can't." Give him the money and the men and he will make a road for the locomotive through any country you like.

But do you know how he does it? Do you know what a tremendous amount of work has to be done before the "first sod" is cut, and with what care it must be done? The problem before the engineer is by no means one of merely getting the line from one place to another. It includes many other considerations, which, if not allowed for, may cause much trouble and expense in the future. For instance, the engineer must decide on the most economical gradient to use. If made very slight it may necessitate the leading of the line around the country and the undue lengthening of the track, with heavy upkeep expenses. On the other hand, an over severe gradient may reduce the first outlay on actual construction but be responsible for ruinous haulage costs. Curves must be kept as gentle as possible, to reduce friction and increase safe speed. The question, "Shall it be a cutting or a tunnel?" constantly occurs, and so do a host of other questions known only to the railroad engineer.

FIG. 1.—A view of the Marshall Pass, Colorado, showing some of the railroad engineering required. The summit of the pass is 10,856 feet above sea-level.
(Photo by courtesy of the Denver and Rio Grande Railroad Co.)

Apart from physical difficulties, there are legal difficulties to be overcome. In countries which are thickly populated, and where land is valuable, the lawyers play a very important part during the preliminary stages of a railway scheme. But with their work we will not concern ourselves—'tis too dusty. Rather let us give our thoughts entirely to the engineers and track-layers, and, as the more difficult includes the less difficult, pay special attention to railroading in mountainous country, where its most signal triumphs have been won.

PRELIMINARY OPERATIONS.

The forerunners, the scouts of the track-laying army, are the survey engineers and their staffs. In a properly worked railroad proposition not a yard of earth or rock is moved on any one section until the centre line of the track has been laid down on paper and transferred to the ground. The costs of the survey average about two per cent. of the total cost of construction, and the money is well spent, since any mistakes made in the first instance prove extremely expensive in the long run.

In earlier days, before the world was as well known as it is now, actual *exploration,* attended by all the

dangers and hardships that befall the explorer, had to precede the survey. Take the case of the Canadian Pacific Railway. For six years separate parties hunted in the Rockies and Selkirks looking for possible paths for the rails. What they suffered may be read in the four hundred pages of a bulky volume collated by Sir Sandford Fleming, the engineer-in-chief. Many routes were suggested, and only after long and careful comparison of their relative merits was the final choice made.

As a rule the railway runs, even in mountainous parts, through regions which have been traversed before, and of which more or less accurate maps exist. In such cases the first expedition is known as the *reconnaissance,* a trip through the country by men of great experience, who rapidly examine the general "lie of the land" and note all the details which are of importance. The engineer, armed with an aneroid barometer, a compass, and an odometer (a wheel of known circumference drawn along the ground to register the distance on a dial), compares elevations, decides how a given rise may be obtained in so many miles; which side of a valley will best serve; where precautions against sand and snow slides must be taken; where a tunnel is unavoidable; and so on.

In mountainous passes the natural fall of the ground may exceed the steepest gradient permitted, and there will be need for "development"—that is, the deliberate increase in the length of the road by

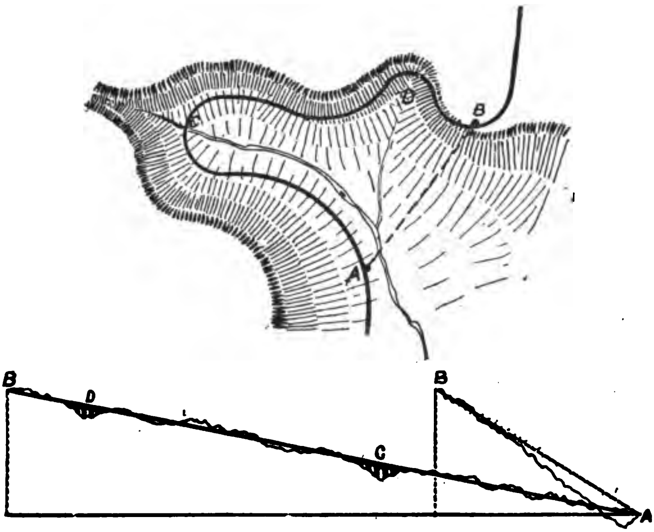

FIG. 2.—The upper diagram shows how the rise from a point A to another point B is negotiated by "developing" the line round the end of a valley. The lower diagram gives the relative gradients of the direct route (A to B) and of the circuitous route (A C D B).

either leading it up a side valley, or making it circle about over itself in tunnels or in the open. Fig. 2 shows in plan and in profile a very simple instance of "development." It is required to get from A to B. The direct line (dotted) has too steep a gradient to

be practicable. But by taking the track round the side of the valley, through C and D, a comparatively gentle gradient is obtained. Turning to existing examples, we have the Marshall Pass section of the Denver and Rio Grande Railroad (Fig. 3), a remark-

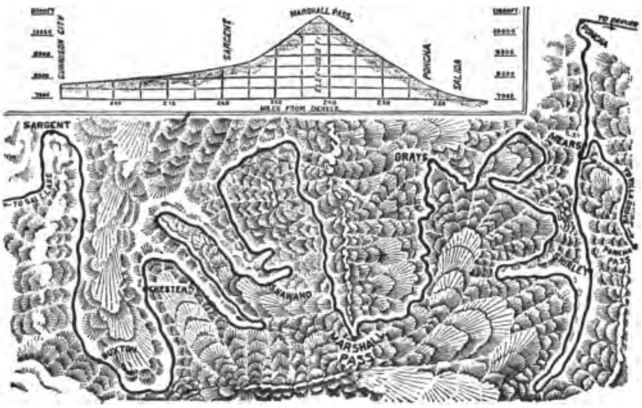

Fig. 3.—The Marshall Pass section of the Denver and Rio Grande Railroad. Observe the extraordinary twists and turns whereby a moderate gradient is obtained.

able feat of development. This famous pass in the Rockies has been subdued by a track that wriggles in and out along the valleys and doubles back on itself in such a manner as to make its length five times that of the direct distance from Sargent to Poncha. Even so it has a rise of four feet in a hundred. Some idea of the country through which it

winds to the summit level of 10,856 feet will be gathered from the illustration on page 22.

Sometimes tunnels must be employed to gain distance in a locality where there are no side valleys. The Albula Railway, Switzerland, includes three very remarkable helicoidal tunnels, two superimposed

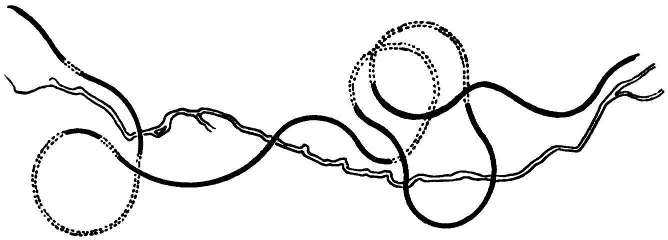

FIG. 4.—Sketch plan of three helicoidal tunnels on the Albula Railway, Switzerland. The tunnels are indicated by dotted lines.

on one another (Fig. 4). The track is led across the river running in the bottom of the pass no fewer than four times. Similar work is found on the St. Gothard Railway. The Darjeeling Railway, in the Himalayas, is also noted for its spirals.

The engineer may have to go over the ground several times before he feels justified in deciding the general position of the line, or submitting several alternative routes, as on his recommendation will be based the succeeding surveys.

PRELIMINARY SURVEYS.

After the reconnaissance comes the *preliminary survey,* in which instruments of precision are used—the *level,* for determining differences in height; the *transit theodolite,* for measuring horizontal angles; and the *chain* or steel tape, for finding the distance between point and point. In front of the party goes

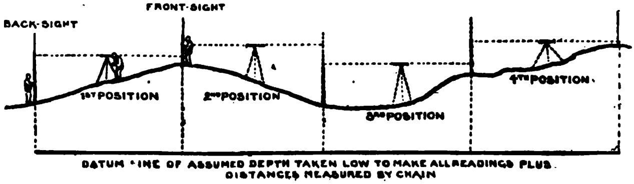

FIG. 5.—To show how a level is used.

a corps of axe-men to clear away bushes, trees, and other obstacles which may interfere with observations. Then comes the transit man, recording angles and distances, and behind him the leveller. One method of using the level is shown in Fig. 5. The man in charge levels the tripod carefully, and turns the telescope on to a graduated pole held vertically at a point behind him by an assistant. The cross-wire in the telescope lies, say, on the 9-foot mark on the pole.

Having got his "back-sight," he revolves the telescope through half a circle, and observes a second pole set up a certain distance away from the first in front of him by assistant No. 2, and finds that the cross-wire cuts this at four feet from the bottom. A very simple subtraction sum shows that the point on which the "front-sight" stands is five feet higher than that on which the "back-sight" stands. Assistant No. 1 now goes forward and sets up his pole, the level is moved to position 2, and the process is repeated. Then No. 2 advances, and so a "profile" or "backbone" line is secured gradually.

For obtaining "contours"—that is, lines plotted on the plan to show differences in elevation on each *side* of the line—the level is set up and the "flag-man" moves away until the reading shows that the foot of his pole is the required number of feet lower than the level. Then the distance between pole and level is measured and recorded on the plan. Contour observations are generally made at right angles to the central line.

It is often a rough life, that of the surveyor, and a dangerous one, too. The theodolite man working along the face of a gorge has at times to trust his life to a rope and be dangled in mid-air while he

records his observations and makes his "bench marks" for future reference. Or perhaps he may be obliged to balance himself on logs slung from chains over a raging torrent, or cling cat-like to an

Fig. 6.—The Denver and Rio Grande Railroad in the Cañon of Lost Souls, Colorado.
(Photo by courtesy of the Denver and Rio Grande Railroad Co.)

ice-slope, with a freezing wind numbing his fingers till they can hardly operate the screws of the transit. But whatever be the physical conditions his observations must be correct, as on them depends to a great extent the fate of the railway.

LOCATION SURVEY.

When the plans and profiles are all completed they are scrutinized at headquarters. If found unsatisfactory, the engineer-in-chief draws a new line or lines, and sends the surveying parties out again, and perhaps a third or fourth time. At last the word is given to definitely *locate* the track by means of pegs driven into the centre line or by marks made on neighboring objects. A railway is a series of straight portions, called *tangents,* connected by *curves.* One of the surveying engineer's most laborious tasks is to "range the curves" in accordance with the plans. Its difficulty depends on the nature of the country. In some cases he has an uninterrupted view and can lay out the curve without shifting his instruments; in others—as for instance when he has to round the shoulder of a mountain—the curve must be picked out piecemeal, by working from point to point and constantly referring back.

THE RANGING OF CURVES.

The instrument used for this purpose is the *transit theodolite* (Fig. 7), which measures angles both vertically and horizontally. It is a telescope mounted

FIG. 7.—A transit theodolite. (Messrs. Stanley and Co., Ltd.)

on standards resting on a circular disc which revolves on a table attached to the top of a tripod. The base is levelled by means of three or four screws between the tripod top and the table.

The telescope can be turned over vertically—transited—between the standards, and the standards revolved with the horizontal disc. Attached to the telescope is a circular scale, marked to degrees and fractions of a degree for comparison with a fixed vernier projecting from the standards. The base is similarly graduated. The user is thus enabled to measure angles both vertical and horizontal.

Curves are set out to a given radius by one or other of several methods. We may begin with the

usual American practice, which is illustrated in Fig. 8. The theodolite is set up at A and sighted back along the straight piece of track or tangent from which the curve springs. It is then transited—turned head over heels—to point towards a point X. If the curve is to be one of "48 degrees," the observer now revolves the telescope inwards horizontally

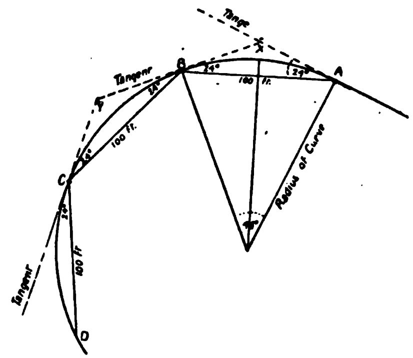

FIG. 8.—Ranging curves (American method).

through *half* that number of degrees till it lies on the line A B, and a spot B is marked on the line exactly 100 feet from A. The diagram explains what is meant by a curve of any particular number of degrees—namely, a curve in which an arc standing on a chord 100 feet long subtends an angle of that number of degrees at the centre of the circle of which the curve is part. The centre may be in the heart

of a mountain, but that makes no difference; the engineer knows that if he lays the angles out correctly the curve will be all right.

Having established his first point, B, he moves his theodolite thither, and sights it along BX, making an angle of 24 degrees with BA. This line BX is the new tangent. The instrument is transited to point towards Y, and the angle YBC turned off, and C is established 100 feet from B; D and other succeeding points are found in the same way until the curve is complete.

In actual practice curves are seldom sharper than 10°. The engineer has tables to show him what number of degrees represent a curve of a certain radius. Thus, if he wished to lay out a curve on a 2,865-foot radius he would turn up his tables and find that this is a 2° curve, and that the angle BAX would be one of 1°. A 10° curve has a radius of 573.7 feet.

In some cases it is possible to sight every point without moving the theodolite (Fig. 9). The engineer sights along the tangent ABC, and turns off an angle CBD, half the number of degrees of the curve, as in the first case; and his assistant places a peg at D, 100 feet from B. He then turns off angle

DBE=DBC, and the 100-foot chain is carried round on D as a pivot till the free end encounters line B. E. This gives him the second point, E. So in succession angles

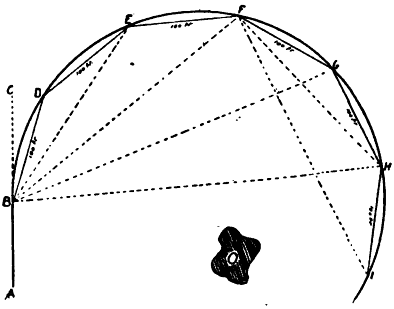

FIG. 9.—Ranging curves from fixed point, by equal angles.

EBF, FBG, GBH, are turned off (all equal to DBC) and points F, G, H, established. The position of the next point, I, is not visible from B, because an obstruction, O, intervenes. Therefore the theodolite is moved to F,

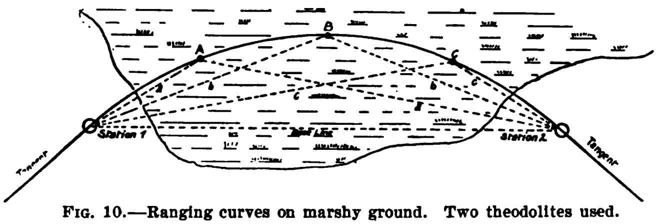

FIG. 10.—Ranging curves on marshy ground. Two theodolites used.

sighted on H, and turned off through the proper angle.

On marshy ground (Fig. 10), where the use of a chain may be impossible, *two* theodolites are set up on the track tangents to be connected, and a man is sent to stake out the points A, B, C on which the two lines of sight meet when the instruments make certain angles with a base line connecting them.

Ranging by "offsets" (Fig. 11) can be done without a theodolite. The tangent is produced along AB for 100 feet, and the measuring chain carried round

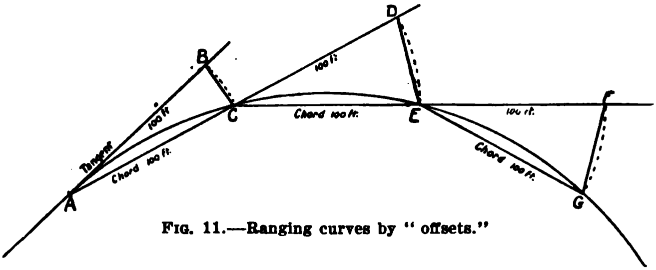

Fig. 11.—Ranging curves by "offsets."

on A into line A C, C being a certain distance from B. Then AC is produced 100 feet to D, and F found by carrying round the chain to E, DE being twice BC. The point G is found by producing CE to F, and offsetting to G, making FG = DE. The degree of curvature depends on the length of the offsets, DE, FG, etc., which are deduced from tables. As a matter of fact, the angle DCE or FEG contains the same number of degrees as CE or EG would subtend at the centre of

the circle. Hence all four methods arrive at the same results.

Some curves are not regular, but increase or decrease in sharpness from one end to the other. These are known as *transition curves,* and are ranged in a manner with which I need not trouble you. Then, again, we have compound curves, bending right or left as well as rising or falling. In mountainous regions most of the curves are of this character.

ROAD CONSTRUCTION.

When the location survey is finished, the construction engineer takes command. The line is divided into sections, and each section let to a contractor, working under the supervision of an engineer. The chief contractors probably sublet the bridge-building and tunnel-driving that may be necessary to specialists in these branches of construction.

The maintenance of an army of men in outlying places is in itself no small task. Huts must be built, and provisions supplied for man and beast, and stores of all kinds and machinery be collected and moved from place to place as the work proceeds.

On a big line operations start at as many points as conditions permit. Where the track will run

through uninhabited country, the rail has to feed itself, and can therefore be pushed out from the ends only. During the building of the Canadian Pacific Railway one army drove westwards across the prairie and the Rockies, while another toiled painfully east-

Fig. 12.—Eagle River Cañon, Colorado, showing new double tracking, one track on each side of the river.

wards from the Pacific coast to meet the first. All supplies had to be taken over the rails already laid.

In open prairie country where there are practically no gradients, and there is a good soil, work proceeds at a great pace, the road-bed being thrown up from

ditches on both sides either by hand or by special machines. The "Canadian Pacific" builders made a tracklaying record of 6⅓ miles in one day. In twenty-four hours 16,000 ties or sleepers were placed, and 2,120 lengths of rail fixed to them with 63,000

FIG. 13.—A steam-shovel at work in a cutting.

spokes. In the Cape to Cairo route *eight* miles have been laid in a day!

The normal rate of progress even in open country is much less sensational, and where big cuts and fills, tunnels and bridges, occur one after the other becomes very slow indeed. In moving "dirt" in cuttings the contractor is greatly assisted by the "steam shovel,"

a huge ladle mounted on the end of a beam, which scrapes three tons or more of stuff from the bank each stroke, and drops it into wagons. It will dig as much in a day as some hundreds of men. Fig. 13 is a picture of one of these shovels at work.

FIG. 14.—A rough contractor's "road" beside a finished track.

The dirt from the cuts is run away over rough "contractors' tracks" (Fig. 14) and either dumped on a spoil bank, or used to make an embankment. The engineer is careful to balance the cuts and fills as evenly as possible, so that there may be little waste of labor. An embankment is formed either by

making it build itself, as it were, the rails being extended along it and the wagons tipped over the gradually advancing end (Fig. 15); or stagings are constructed across the depression and the fill is made from the centre outwards, the staging being gradually removed as the bank increases.

FIG. 15.—Forming an embankment by end-tipping. The "tip-heads" are separated by "gullets" (depressions), to be filled by side-tip wagons.

The steepness of the sides of a cutting depends on the nature of the material. Through rock and chalk they may be perpendicular, but where sand and clay occur the inclination of the slope to the horizontal must be the "angle of repose" of the substance. Wet

clay is the most troublesome material, as it will not stand a steeper slope than 16 degrees. Next to it comes sand. The drainage of the sides of a cutting is effected by digging deep trenches and filling them with chalk, stones, or other stuff (Fig. 16), through

FIG. 16.—Draining the side of a cutting by trenches filled with chalk. (*Photo, Great Western Railway Co.*)

which the water can easily find its way to drains laid at the foot of the slopes (Fig. 17). The amount of earth moved in the building of some lines is enormous. On the South Western Railway, between London and Southampton, it was calculated that the

aggregate earthworks represented a mass sufficient to form a pyramid having a base of 150,000 square

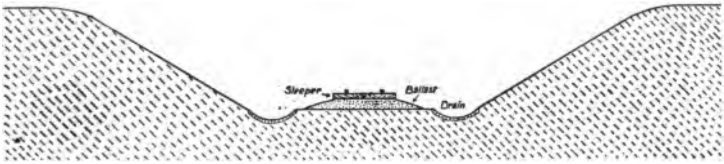

FIG. 17.—Section of a cutting, showing drains, ballast, ties, and rails.

yards and a height of 1,000 feet; and even these figures have been exceeded elsewhere.

BLASTING THE ROCK.

Earth work is, however, very easy compared with the blasting of a ledge along the face of a rocky gorge, such as that at Lengue on the Benguela Railway in Portuguese South-West Africa. In order to keep well above the level of the watercourse it was decided to carry the line along the cliff at the side of the gorge. The rock was so hard that it could be removed by blasting only. Here is a little pen-picture of the operations as given in *The World's Work:* "Work was carried on night and day. An electric lighting plant was brought up from the coast and installed at the railhead, while across the gorge cables were stretched from which lamps were suspended. In the


FIG. 18.—Blasting rock for the track: before the explosion.


FIG. 19.—The same: after the explosion.
(*Photos, Great Western Railway Co.*)

fitful gleams of the blue light thrown by the electric arc lamps the natives worked away in the dead of night with the rock-drills, boring holes for the insertion of the dynamite blasting cartridges.....When the holes were driven right into the rock-face and the cartridges had been tamped home, the electric lights were hauled along the cables to a safe distance from the force of the concussion, while the natives also retired out of danger's way. In the stillness of the night there would suddenly be heard the dull, muffled roar of the blasting charges, growing in intensity as the rock disintegrated, and amid a cloud of heavy smoke, dust, and débris a gaping hole was torn into the side of the rock cliff....Immediately after the explosion had died away the natives scampered to the rock-face once more and set to work with their drills as if their lives depended upon it, while other gangs began vigorously clearing away the masses of rock disintegrated by the previous explosion, and levelling down the ground ready for the rails, which were laid as quickly as possible. Day and night this went on, with the gangs working in shifts, until after a few weeks the top of the gorge was reached. In excavating this section of the line several million tons of rock were moved....Throughout

this stretch the line is flanked on one side by a perpendicular wall of granite rising sheer for several hundred feet. On the other side there is a corresponding drop into the valley below."

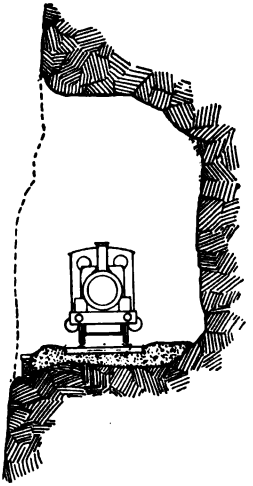

FIG. 20.—Track in a rock ledge. The dotted line shows the original extent of the rock.

Tunnel making and bridge building are treated in other chapters, so, although they occasion some of the most difficult work in railway construction, they need not be described here in detail. We may spare a word, however, for the wonderful trestles that are thrown across deep valleys and swamps, some rising hundreds of feet into the air, and apparently far too frail for the load they have to carry; some sweeping in wide curves. An immense amount of timber is used in these bridges, but there is a general tendency nowadays to substitute steel for such inflammable material.

Occasionally the engineer experiences great trouble in securing a firm foothold for the trestle-feet. A notable case is that on the "Lucin cut-off" which

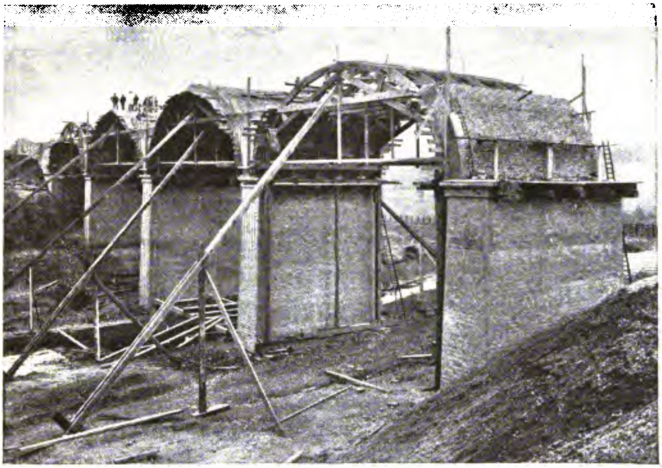

Fig. 21.—The building of a brick railway bridge, showing the wooden "centres" or supports for the arches during construction.
(*Photo, Great Western Railway Co.*)

Fig. 22.—Steel "centres" used in building arches of bridge at Mount Union, Pennsylvania Railroad.
(*Photo, Pennsylvania Railroad Co.*)

the Southern Pacific Railway has pushed across one end of Great Salt Lake, Utah. In the deeper water long piles to carry the track were driven into what appeared to be hard solid ground, but afterwards proved to be only a crust of salt and sand on the top of a soft substratum of great depth. The piles sank in and the trestles collapsed. Then the engineers tried to make a solid embankment of rock; but the material was swallowed up without effect, though some thousands of tons were emptied daily for several weeks. Finally, it was decided to base the trestles on timber cribs filled with stone and sunk to the bottom of the lake. The laying of ten miles of cribs through deep water has been a task that exceeds even the filling-in of Chat Moss, between Liverpool and Manchester, by the redoubtable George Stephenson.

SNOWSHEDS.

Where the railway rises above the snowline and skirts slopes down which avalanches may rush at certain seasons, it is necessary to protect the track by miles of snowsheds. These are constructed of very stout timbers, and either anchored to the hill-side so that the roof forms a continuation of the slope, as in Figs. 23, 24, and 25; or made of "double

span" shape (Fig. 26) where they have to withstand a vertical fall. Weight is given to the structure by

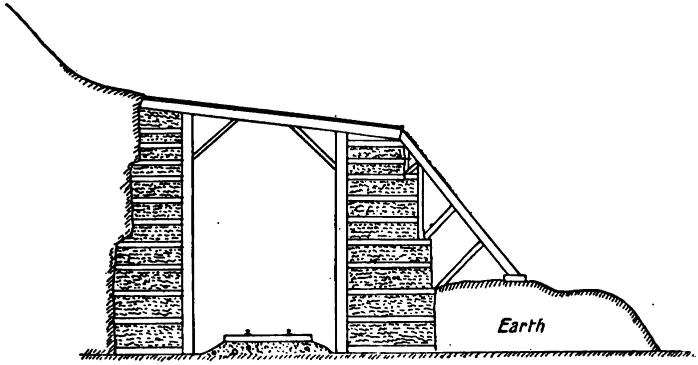

FIG. 23.—Snowshed.

attaching it to cribs filled with rock. The woodwork being very inflammable, and the shape of a tunnel such as to assist the spread of flames, it is necessary

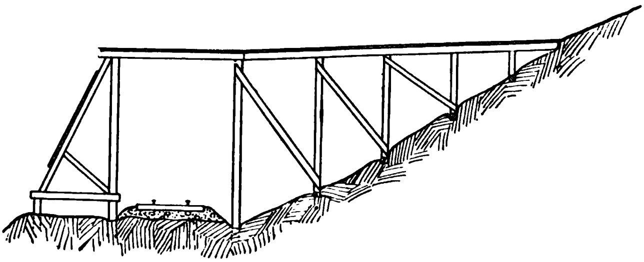

FIG. 24.—Snowshed: another type.

to install fire-extinguishing apparatus and establish fire pickets. Also, as a further precaution, the shed

is broken into short lengths by "fire-breaks," to isolate a conflagration. At a fire-break the snow is

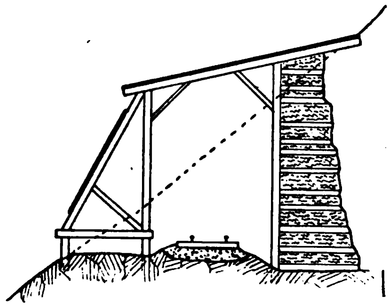

FIG. 25.—Snowshed: another type.

deflected from the uncovered track by V-shaped cribs with the apex pointing up-hill (Fig. 27). On the Southern Pacific Railroad the snowsheds contain telescopic portions, which are closed during the stormy

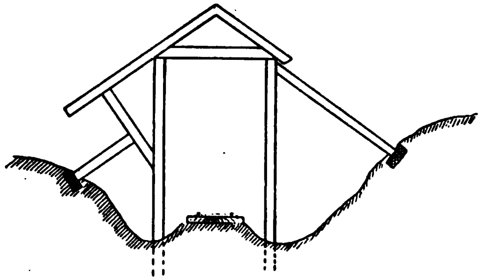

FIG. 26.—Vertical-fall snowshed.

season, but opened in summer or in event of a fire. The movable lengths, about fifty feet long, run on

wheels on a wide-gauge track laid outside the main track. They are easily moved in or out of the larger fixed parts of the shed by a locomotive or man-worked tackle, and have successfully stopped what might have proved very serious outbreaks of fire. The longest stretch of snowshed is on the Central Pacific Rail-

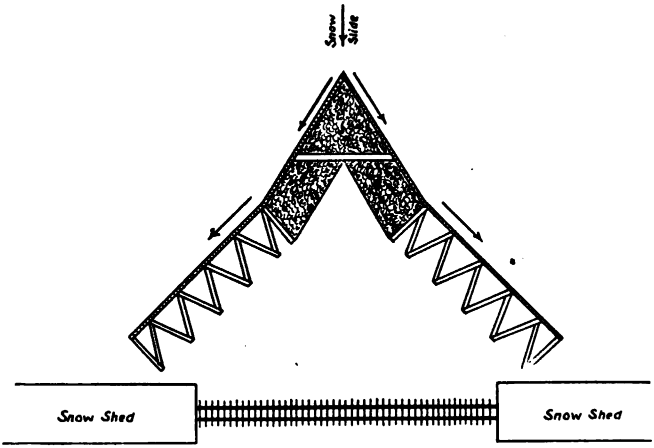

Fig. 27.—V-shaped crib to deflect snow from an opening in a snowshed.

road, where it crosses the Sierra Nevada. For thirty-three miles the track is continuously protected. Three "fire trains" are always ready, with steam up, to carry the fire brigade at a moment's notice to any threatened spot, when the watchmen, who are on duty night and day, telephone the necessary information.

Fig. 28.—Snowshed on Canadian Pacific Railway.
(Photo, Wm. Notman and Son, Montreal.)

LAYING THE TRACK.

When the road bed has been graded, it is covered to a depth of about a foot, and for an average width

of 10 feet, with "ballast"—that is, gravel, or stone broken up till it will pass through a 2-inch ring. This is drawn on by carts, and spread very carefully to the required surface, and affords a firm and well-

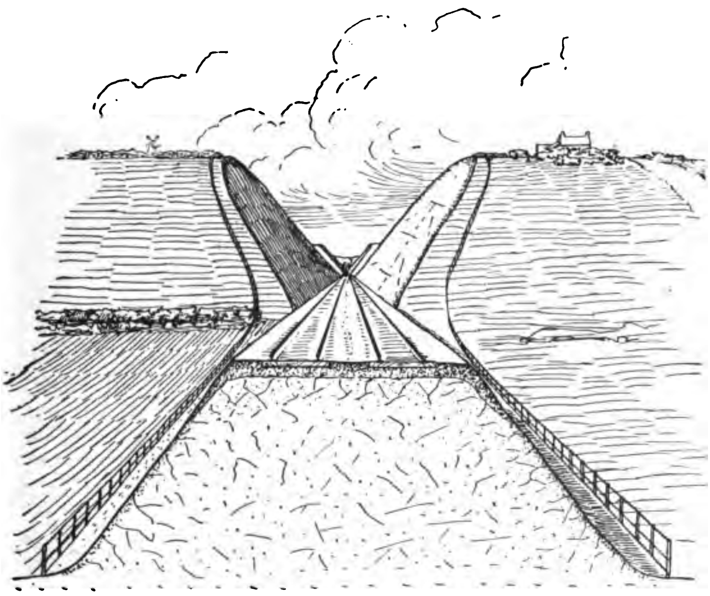

FIG. 29.—Cutting and embankment.

drained foundation for the sleepers or ties. These last are usually of pine, treated with creosote or some other preservative. *Creosoting,* the most commonly used process, is done as follows: The ties are piled on iron carriages and run into a long iron cylinder,

the ends of which are then fastened on and made air-tight. For several hours the space inside is alternately exhausted of its air by a vacuum pump and filled with steam, to extract the air and water from the pores of the wood. Finally all the air is drawn out, hot creosote oil injected, and air-pumps set to work to create an air-pressure of 100 lbs. to the square inch. This forces the creosote into the pores of the wood. At the end of a couple of hours

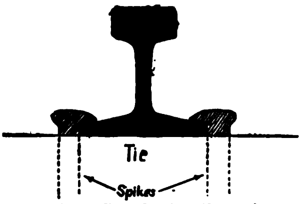

FIG. 30.—Standard rail section.


FIG. 31.—Bull-headed rail in "chair." K is the wooden key to hold rail tight.

or so the oil is drawn off, the cylinder covers are removed, and the ties are pulled out ready for laying and spacing.

The standard section of the "flat-footed" rail used in the United States and most other countries is shown in Fig. 30. The rail is attached to the tie by a pair of spikes, driven out of line with one another, the heads overlapping the lower flange. In the British Isles and in some Continental countries the "bull-headed" rail (Fig. 31) is employed. Heavy

cast-iron "chairs" are bolted to the ties before they are laid, and in these the rail rests, wood blocks (K) driven in between its outer side and the chairs holding it firmly in position. This system of rail laying makes the replacement of rails a very easy matter, and it is free from the trouble of loose spikes. But it is more expensive in the first instance, and so does not find favor on lines where economy is of first importance.

At curves the outer of a pair of rails is "superelevated" to give the train a tilt inwards and counterbalance the centrifugal force which, were both the rails on a level, would tend to throw the wheels off the track. The superelevation is proportioned to the speed at which the trains will be permitted to take the curve. On express routes, where the tilting is considerable, it may be felt distinctly by the traveller. Many accidents have been due to drivers exceeding the speed limit for which allowances were made by the track layers.

THE LAST SPIKE.

The cutting of the first sod of a railway is often a great ceremony. Bands play; and a procession is formed and marched to the spot where the function

Fig. 32.—Royal Gorge, Grand Cañon, the Arkansas, Colorado. This is the deepest chasm in the world through which a railroad passes. The walls rise 2,627 feet above the track. In the background are seen the girders supporting a hanging bridge.
(*Photo, Denver and Rio Grande Railroad Co.*)

is to take place. The chairman makes a speech and the engineer-in-chief hands him a silver-bladed spade,

with which he digs out a sod and transfers it to a barrow of elegant design. Everybody cheers, and then there is a general move to the tent or building where a great banquet has been prepared.

Years pass, and the day arrives when the last spike is to be driven. Though this marks the completion of a great work, it is often accompanied by very little of the shouting that was heard when everything remained to be done. In many cases this is only natural, as the rails started from a thickly populated spot, and the last spike may be driven in the midst of a wilderness. Yet the closing scene is really far the more dramatic.

Sir Sandford Fleming has described in eloquent words the last episode in the building of the Canadian Pacific Railway. They are well worthy of quotation.

"Early on the 7th [of November, 1885] the junction was verging to completion, and at 9 o'clock the last rail was laid in place. All that remained to finish the work was to drive home one spike. By common consent, the duty of performing the task was assigned to one of the four directors present, the senior in years and influence, whose high character placed him in prominence—Sir Donald Alexander

FIG. 33.—Mountain Creek trestle bridge, Canadian Pacific Railway. It contains 1,500,000 feet of timber.
(Photo, Wm. Notman and Son, Montreal.)

Smith. No one could on such an occasion more worthily represent the Company or more appropriately give the finishing blows, which, in a national cause, were to complete the gigantic undertaking.

"Sir Donald Smith braced himself to the task, and he wielded the by no means light spike hammer with as good a will as a professional tracklayer. The work was carried on in silence. Nothing was heard but the reverberation of the blows struck by him. It was no ordinary occasion; the scene was in every respect noteworthy, from the group which composed it and the circumstances which had brought together so many human beings in the heart of the mountain, until recently an untracked solitude. Most of the engineers, with hundreds of workmen of all nationalities, who had been engaged in the task, were present. Every one appeared to be deeply impressed by what was taking place....All present were more or less affected by the formality which was the crowning effort of years of labor, intermingled with doubts and fears and oft-renewed energy to overcome what at times appeared unsurmountable. To what an extent the thoughts of those present were turned to the past must, with that undemonstrative group, remain a secret with each individual person....The

Fig. 34.—A mammoth locomotive, built by the American Locomotive Co., Schenectady, for the Erie Railroad. Weight, 286½ tons; length, 80 feet; heating surface, 5,314 square feet; tractive effort, 60 tons.

blows on the spike were repeated until it was driven home. The silence, however, continued unbroken, and it must be said that a more solemn ceremony had been witnessed with less solemnity. It seemed as if the act now performed had worked a spell on all present. The abstraction of mind, or silent emotion, or whatever it might be, was, however, of short duration. Suddenly a cheer spontaneously burst forth, and it was no ordinary cheer. The subdued enthusiasm, the pent-up feelings of men familiar with hard work, now found vent. Cheer upon cheer followed, as if it was difficult to satisfy the spirit which had been aroused. Such a scene is conceivable on the field of hard-fought battle at the moment when victory is assured.

"Not unfrequently some matter-of-fact remark forms the termination of the display of great emotion. As the shouts subsided, and the exchanges of congratulations were being given, a voice was heard in the most prosaic tones, as of constant daily occurrence: 'All aboard for the Pacific.' The notice was quickly acted upon, and in a few minutes the train was in motion. It passed over the newly laid rail, and amid renewed cheers sped on its way westward."

FIG. 35.—Low-pressure cylinders of 286½-ton locomotive.
(*Photo, American Loco. Co.*)

RACK RAILWAYS.

When the gradient exceeds 4 feet in 100 it is economical, and may be necessary, to make a rack railway. The rack is laid between the ordinary smooth rails, and engages with the teeth of a large cog driven by the mechanism of the locomotive. Switzerland contains the majority of the well-known rack railways—the Pilatus, Rigi, Wengeralp, Zermatt, Rothhorn, Jungfrau among them—but most mountainous tourist resorts in other countries can boast

one or more examples. Of the Swiss the Jungfrau is the most extraordinary. It starts at Kleine Scheidegg, 6,710 feet above sea level and climbs up in the open to Eigergletcher (7,560 feet). Then it plunges into a succession of tunnels, between which the traveller gets glimpses of splendid prospects, and winds slowly up past Rothstock, Eigerwand, Eismeer, and Jungfraujoch stations—cut in the solid rock—to a point 216 feet below the summit of the mountain, which is 13,886 feet above sea-level. A lift, operated by electricity, as is the railway itself, transfers passengers to the actual summit, which commands a splendid view of the whole Alpine region of Switzerland.

The railway is for the most part a tunnel through limestone and gneiss. It took nearly five years to survey the course, owing to the extreme difficulty of finding stations for the instruments, though it is only a few miles long. But by way of compensation the construction could be continued in winter as well as summer, as the workmen in the tunnels were protected from the cold outside. Also the proximity of the tunnels to the face of the cliff made it easy to get rid of the rubbish by driving short cross tunnels to the face at intervals, and dumping it down the mountain-side.

The track has a gauge of 3¼ feet (one metre). The engine will move a train and eighty passengers up the steepest grade (1 in 4) at an average speed of about 5 miles an hour. To control the descent there are three separate brakes, each capable of stopping the train by itself. And so any one can easily ascend and safely descend the peak which once was accessible only to the daring mountaineer.

PIKE'S PEAK RAILWAY.

More than a hundred years ago Lieutenant Zebulon W. Pike, in command of a squad of private soldiers, guides, and Indians, was exploring the Rockies when he sighted in the distance a "great white peak," which appeared to him quite inaccessible to man. Eighty-five years later there was completed a cog railway running from Manitou Station, on the Denver and Rio Grande, to the summit of the peak named after the bold explorer. Manitou is 6,000 feet above the sea; the Peak lies 8,108 feet higher, and the rise is managed by a track rather less than 9 miles long, having an average gradient of 19 feet in 100. The road-bed is solid and from 15 to 20 feet wide, leaving fully 5 feet on each side of the cars. At intervals of 200 feet the track is anchored to solid masonry to prevent any possibility of its sliding on

its bed. Every locomotive has three cog and pinion appliances, which can be worked together or independently. In each cog is a double set of pinion brakes, either one of which can stop the engine in ten inches, up hill or down, on the steepest gradient

Fig. 36.—Pike's Peak Mountain Railway in the winter.
(Photo, "Cassier's Magazine.")

and when travelling at the maximum speed allowed. The car, which is not coupled to the locomotive—always at the down-hill end, so as to reduce the danger of derailment—is itself furnished with separate brakes. Even during the tourist season snow-ploughs have to be used frequently to keep the track open.

This loftiest of rack railways gives the sightseer the most glorious views, and at the same time impresses him by the wonderful character of the engineering that made it. No physical obstacle was sufficiently formidable to check the upward progress of the track. It skirts giddy precipices, down which one looks shuddering but safe, and finishes with a straight climb on a gradient of 25 in 100 to the Peak, where the tourist may ramble and feast his eyes to the full.

Yet this railway does not climb so far skywards as one in Peru worked by ordinary adhesion locomotives. The Callao-Oroya line, built in the seventies by Henry Meiggs, the famous contractor, rises 15,665 feet in its 140-mile course through the Andes. For 100 miles the track climbs continuously, winding and zigzagging in a most extraordinary manner, crossing streams on dizzy bridges, burrowing through the rocks, creeping along tremendous precipices. At one place it was necessary to make a reversing switch in a tunnel—a unique feature. The railway is one of the most extraordinary feats of engineering ever accomplished by man, and I regret that lack of space forbids a fuller description.*

* The reader will find further information about this road in "The Romance of Modern Engineering."—A. W.

Chapter II.

A RAILWAY THROUGH THE SEA:—
TRAIN FERRIES.

The Florida Keys—A great project—Difficult surveying—Labor troubles—Embankments made by dredges—Vast quantities of materials transported by sea—A railway of viaducts—Work at Key West—A train ferry to Havana—Other train ferries—Sea ferries—How a train is embarked and landed—Danish ferries—Ferries on the Great Lakes—The *Baikal.*

IF you consult a good-sized map of Florida and the Gulf of Mexico, you will notice a chain of small islands stretching out like a long tail in a south-westerly curve towards Cuba from the south-east corner of the peninsula. These islands, mostly coral reefs covered with swamps, and known as the Florida Keys, have until recently been of little value to the United States, with the exception of Key West, the most southerly, which rose into prominence as a naval station during the Spanish-American war of 1898. From Key West to Havana, in Cuba, is a distance of 90 miles or so, only a few hours' voyage. Now, the United States have great interests in Cuba,

and for this reason Key West has become the terminus of a railway connected with the systems of the mainland. "A railway?" you may ask. "But Key West is separated by many leagues of sea from Florida!" Yes, but the Keys string out in line across the bay for two-thirds of the distance, and the water between them is comparatively shallow, and so, through the enterprise of one man, Mr. Henry M. Flagler, owner of railways and hotels galore on the east coast of Florida, the engineers bridged island to island until they made a secure way for the locomotive from Miami to Key West—130 miles of some of the most extraordinary railway work ever accomplished. This really is a railway through the sea, for at places the traveller, looking from the car window, has nothing between him and the horizon but the waters of the Gulf and the Atlantic Ocean.

The undertaking was accompanied by immense difficulties. The surveyors who went out to seek a path through the Everglades, the almost impassable morasses and wilderness that cover the southern part of the peninsula, to Cape Sable, suffered as few surveyors have suffered; and the making of observations among the Keys was anything but a picnic, since much of the work had to be done afloat, amid the

foul exhalations of mangrove forests and clouds of thirsty mosquitoes. Some of the Keys are so low and so far apart that towers had to be built on them to raise the theodolites to a sufficient height to view land across the straits.

The actual construction was handicapped by the refusal of the better class of railroad men to take part in a scheme that necessitated their living largely on houseboats, among the most dismal surroundings. The hands that were collected by the energetic general manager, Mr. Joseph R. Parrott, proved tough, and in many cases useless, customers, who would have been unmanageable had not the authorities rigorously suppressed the sale of alcoholic liquors. Yet many of them were brave fellows, otherwise the enterprise would not have reached completion.

Starting from Miami, on the mainland, the track was pushed for thirty miles through the outskirts of the Everglades to the Keys. On this portion of the work powerful dredges were set to excavate two parallel canals and pile up the mud into an embankment between them. On the top of this the first stretch of rails was laid. When the Keys were reached, the coral and limestone of which they consist had to be blasted and heaped. It was possible to span the

smaller sea gaps and the lagoons with mud embankments accumulated by very shallow-draught dredges of special construction, but the larger gaps required trestle-work and the building of long arched viaducts of reinforced concrete, fringed with walls to protect trains from the wind and water when a hurricane swoops down on the Gulf. One gap is four miles, another two miles, and a third, from Knight's Key to Bahia Hondo, seven miles across. The last of these is bridged in part by a viaduct of 120 arches, resting on twenty-eight piles each, capped with a 9-foot layer of concrete. Of cement 300,000 barrels, of rock 200,000 cubic yards, of timber 3,000,000 feet, and of steel reinforcing rods 7,000 tons have been consumed in this one link, and large as the figures appear they repre-

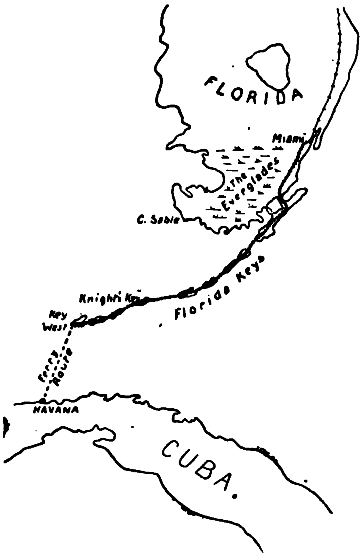

FIG. 37.—Sketch map to show the track of the Florida East Coast Railway Extension across the Florida Keys.

sent but a small part of the total material required for the railway, all of which was brought to the scene of operations on shipboard. The mere transportation of such bulk employed a large fleet of vessels, and hundreds of flat-bottomed boats to land the stuff through the shallow waters surrounding the islands. Hardly less formidable was the task of feeding and housing several thousands of workmen in a region remote from any large base of supplies.

The railway is practically a series of viaducts and embankments. Thirty miles of open sea are traversed; thirty miles of swamp and lagoon. Several storms have scattered the working force from time to time, and taken their toll of human life, but the waves have made no impression on the great barrier that now checks their career.

To make a fit terminus for the railroad at Key West long walls have been built near the sea-front and huge quantities of mud lifted over them by suction dredges from the sea-bottom. Thus at one operation is obtained a large area of reclaimed land and a deep-water roadstead for shipping. From Key West great steam ferries transport trains bodily to Havana. It is thus possible to travel, without changing cars, from New York to Havana in forty-

eight hours. From Havana to Santiago, on the south-east coast of the island, is a run of another twenty-four hours; and thence to the Isthmus of Panama, a fifty-hour voyage. So this strange railway brings New York within six days of the Panama Canal, a fact that in itself is of the greatest importance, apart from the revival of prosperity in Cuba which such easy communication must eventually lead to. And all this has happened because one man put down $15,000,000 and said, "No matter what the difficulties may be, I want a railroad made across those coral reefs." And his behest has been obeyed with a speed that reflects the highest credit on all concerned, for the Florida East Coast Railway Extension was begun only in 1905.

OTHER TRAIN FERRIES.

A short review of the world's chief train-ferry systems will no doubt interest the reader. The majority of these form part and parcel of the great American lines which link up districts separated by large sheets of water. To take the *Sea Ferries* first.

The New York, Philadelphia, and Norfolk Richmond Co. operates a train ferry from Cape Charles to Norfolk, across Chesapeake Bay, a distance of 36

miles. The ferry line includes a number of flat cargo barges, some fitted with three rail tracks, the rest with four tracks. These floats are towed to and fro by tug boats, over waters that are often as rough as those of the open sea. "Upon arriving at the terminals, the barges are secured to bridges, which are carried on water-tight pontoons, rising and falling with the tide. These bridges are fitted with four toggle bars which engage in four toggle eyes on the end of the barges, for the double purpose of centering the barge with the bridge, so that the rail ends on each may fit together, and of maintaining its height. The barges are held to the bridges by steel mooring cables, attached to large mooring eyes on the decks, and drawn taut by winding machinery on the bridges. ....The cars are drawn off by a locomotive."

The utility of this ferry may be gathered from the fact that it transports over 60,000 cars and 700,000 tons of freight every year.

New York Bay is the scene of the operations of four ferry lines, handling millions of tons of freight annually. The longest trip is one of 8½ miles, from Long Island to Greenville Station.

On San Francisco Bay we find the *Solano,* one of the largest ferry steamers in existence, at work. With

a length of 424 feet and a beam of 64 feet, she is able to accommodate on her 4 rail tracks 27 passenger or 42 freight cars.

In European waters a steam ferry forms links in the railway service between Berlin and Copenhagen. Arriving at Warnemünde, on the Prussian coast, the train is transferred on to a steamer which carries it to Gjedser, on the island of Falster, 26 miles away. A short land journey follows to Orehoved, at the north of the island, where the train goes to sea once more. It lands at Masnedoe, and then has a clear overland run to the Danish capital. Copenhagen has train-ferry connection with Malmoe in Sweden; and there are five other ferries linking up the various parts of Denmark.

LAKE FERRIES.

A map (Fig. 38) shows the routes and lengths of the several ferry systems on Lake Michigan, which has a breadth of 84 miles and a length of 345 miles. The strong gales which at times vex this large sheet of water raise waves 20 to 25 feet high, and in winter fogs and ice render navigation difficult and dangerous. Yet the great ferry steamers and train barges ply to and fro, the steamers being built to cut through ice

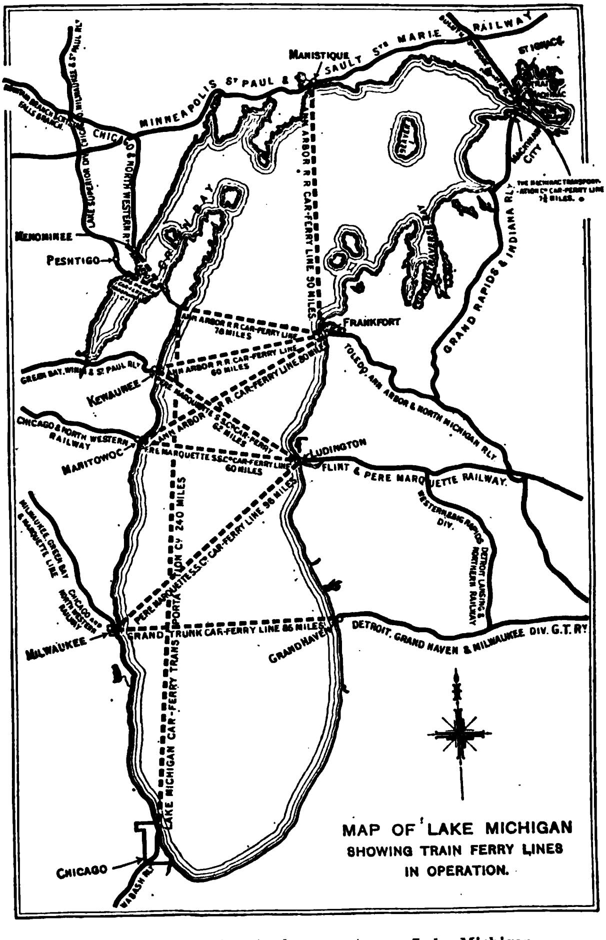

FIG. 38.—Map of train ferry routes on Lake Michigan.
(By permission of E. de Rodakowski, Esq.)

4 feet thick. The efficiency of these ice-breaking steamers led the Russian Government to build the *Baikal* train ferry, which for some years transported the trains of the Trans-Siberian Railway across the lake after which it was named. The *Baikal* is a vessel of 4,000 tons, built up of pieces that had to be transported by sea, rail, and river from Newcastle-on-Tyne to the lake, where they were assembled under the eye of English engineers.

Chapter III.

THE BUILDING OF A BIG SHIP.

The ocean liner—Shipbuilding—Two mammoth vessels—Planning a ship—Sheer draught—Detail drawings—Experimental model—The building sheds—The structure of a ship—Keel, frames, floors, and other details—The skin of a ship—Shipwrights at work—Assembling the framework—The plating—Riveting—Preparations for the launch—Moving and standing ways—Greasing the ways—The drags—The launch—The engines of the big ship—Huge turbines—Fitting out the ship—The official trials—Ruskin on ships.

THERE are few, if any, more magnificent sights than a huge steamship cleaving her way full speed ahead through the open sea or coming majestically to her berth at the pier side. Her towering funnels, her huge hull, contrasting in size so strongly with the pigmy passengers and crew, make one wonder how puny man can fashion such an enormous ark to carry thousands of his kind across the raging waters of the ocean, for but few of us have ever seen a "liner" in the making.

Now, shipbuilding is a very complicated business,

founded upon many mathematical formulæ formidable enough to frighten a seeker after knowledge if he happen to pick up a technical book on the subject. Even the practical work of piecing together the thousands of parts that go to the making of a ship requires very skilled labor, and very careful labor, too, since nothing but the best is good enough for the leviathan which will be called upon to withstand the hardest buffets of Father Neptune. If you strolled into a shipyard and asked for information, you might be much mystified by the names of things, as the most kindly of instructors would necessarily use at least some of the technical terms to which he has always been accustomed.

However, it is impossible to keep a description of shipbuilding out of a book that deals with great feats of engineering, so I mean to make an attempt to give you a fair idea of how a monster ship is designed and built.

In order to be well up to date I will select as example the huge quadruple-screw *Mauretania,* which, like her sister ship, the *Lusitania,* created such interest both inside shipping circles and out when she was launched, and made her bid for the "blue ribbon" of the Atlantic. The *Mauretania* broke the record

foul exhalations of mangrove forests and clouds of thirsty mosquitoes. Some of the Keys are so low and so far apart that towers had to be built on them to raise the theodolitès to a sufficient height to view land across the straits.

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in size as well as speed, being 790 feet long "over all," 88 feet in the beam, and having a draught of 33½ feet at a displacement of 38,000 tons. To drive this huge mass through the water at the contract speed of 25 knots per hour, 68,000 horse-power had to be developed by the engines, which—and this made these ships all the more interesting—were of the Parsons turbine type. Twenty-five boilers, weighing 100 tons or so apiece, and affording between them 3½ *acres* of heating surface, supply the steam to work the six turbines. We shall come to a more detailed account of the machinery later on, and may therefore pass at once to some general remarks on

THE PLANNING OF A SHIP.

When the owners of a vessel that is to be have made up their minds as to her size, speed, and capacity, *drawings* have to be got out. These fall under two heads: (1) the sheer draught; (2) detail drawings, plans, and sections of the ship.

To take them in order. The SHEER DRAUGHT consists of drawings showing the dimensions and shape of the vessel's outer surface *before* the plating is put on—that is, the outside dimensions of the mere framework. As a ship has length, breadth, and depth,

it is necessary that there should be three of these drawings, the measurements in which must coincide exactly. You may imagine, first, that the ship is cut down the middle from stem to stern, and each half further subdivided vertically lengthwise through planes parallel to the centre plane. The inside edge, as it were, of every one of these slices is shown in the *elevation,* or *sheer plan.*

The elevation has parallel horizontal lines drawn from end to end at equal distances from one another. These are known as the "water lines," which we meet again in the *half-breadth plan,* showing one-half (longitudinally) of the vessel as seen from above, with the curves which it has at the successive water lines.

Then again the vessel must be considered endwise. On the "elevation" are equally spaced vertical lines, termed "square stations," from stem to stern. The *body plan* shows the curves that the vessel has if cut squarely across at these square stations.

The lines of all kinds are carefully numbered for reference and comparison.

The DETAIL DRAWINGS comprise (*a*) the *profile,* or section from end to end, showing how the decks and bulkheads are to be placed; (*b*) the *deck and hold*

plans, showing the various decks as seen from above; (*c*) the *midship section* and other transverse sections needed to show the arrangement and sizes of the frames, plating, and other parts used in construction.

FIG. 40.—One of the *Mauretania's* anchors. Weight, about 10 tons. Made by Messrs. N. Hingley and Sons, Netherton.

It is therefore apparent that each sheer draught drawing has its counterpart among the detail drawings. It should be mentioned that they are all made on a reduced scale of ½-inch or ¼-inch to the foot, so there is all the greater need for absolute accuracy

in order that the enlarged drawings—of which we shall speak presently—may be "fair."

In the case of a vessel which in design, size, and speed is to differ from existing examples, it is necessary for the designers or builders to make experiments with a model before finally deciding on dimensions, lines, power of engines, etc.

THE EXPERIMENTAL MODEL.

This is usually a wooden block or a hollow casting of paraffin wax, shaped to the contours of the sheer draught by special machines. When it has been finished and polished, it is transferred to an experimental tank,* and loaded until it sinks to a certain level. A large carriage spanning the tank tows it through the water at speeds which are mechanically recorded, as are also the pull required to move the model at any given speed, and many other particulars. If the resistance proves to be excessive the shape of the model is altered until it gives satisfactory results; and from it the final designs are made.

In the case of the *Mauretania* the wax model was supplemented by a large launch, 47½ feet long,

* That at Haslar, near Portsmouth, used by the British Admiralty, is 400 feet long, 20 feet wide, and 9 feet deep.

driven by electric accumulators and motors carried on board, run in a large dock on the river Tyne. It was built of wood, and so constructed that its shape and the positions of the propellers could be modified within certain limits. By means of delicate instru-

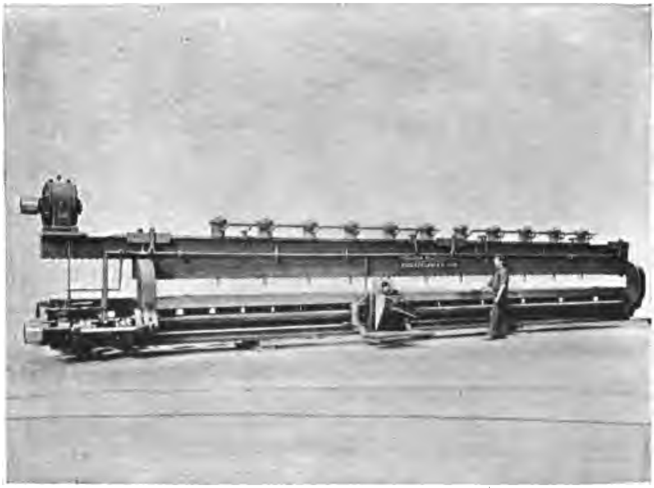


FIG. 41.—Huge planer for ship's plates. Messrs. Wm. Sellers and Co., Philadelphia.

ments information of many kinds was collected as regards the best shape of the stern; the effect of wind; the best relative position, speed, and curvature of the propellers; friction of the launch's surface against the water, etc. In passing it is interesting to notice that the several designs of propellers recommended

by different authorities as the most efficient were found to vary among themselves by as much as 12 per cent. in their actual efficiency. In the case of a ship of the size of the *Mauretania* the wastage of 12 per cent. of its engine power would mean a huge extra coal bill every trip, and the experiments would have been justified had they only served to prevent such a loss of power as the adoption of a bad design of screw would have occasioned.

THE BUILDING-SHEDS.

The task of building the *Mauretania's* hull was entrusted to Messrs. Swan, Hunter, and Wigham Richardson, Ltd., of the Wallsend Shipyard, Newcastle-on-Tyne. As the vessel was to be much larger than any—the *Lusitania* excepted—that had ever been launched, it was necessary to lay down special building-berths for the purpose. The vast sheds, under one of which the *Mauretania* came into being, are 750 feet long, 150 feet high, and 100 feet wide inside. As the roof is glazed work can be carried on in all weathers without discomfort, and powerful arc lamps give sufficient light for the men to ply their tools by night. A notable feature of the berth is the arrangement of cranes, which (see Fig. 42) run under

the roof on rail girders attached to the beams. Loads of 40 tons can be picked up by these cranes if several

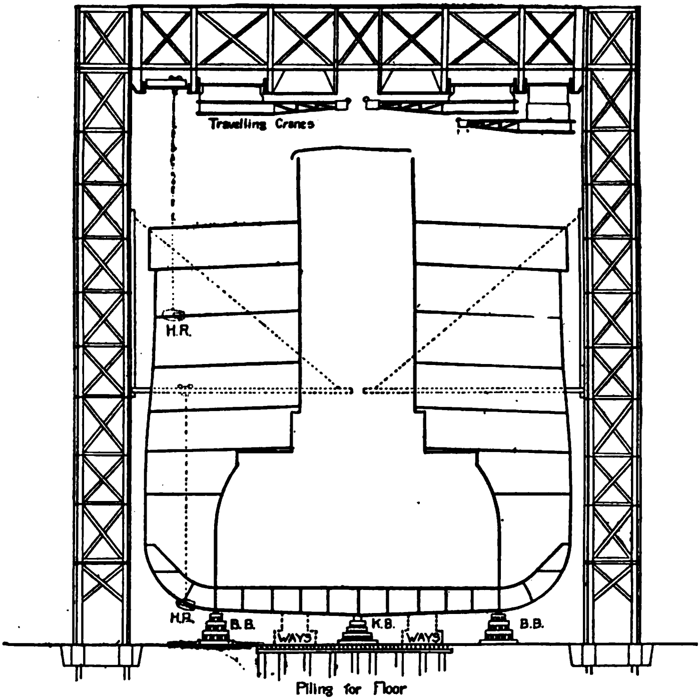


FIG. 42.—Diagram of shed in which the *Mauretania* was built at the Wallsend Shipyard. H R = hydraulic riveter; B B = bilge blocks; K B = keel blocks. (*By permission of "The Shipbuilder."*)

be used in concert. The dotted lines in the diagram indicate booms from which hydraulic riveters, H R,

are suspended while at work on the rivets of frames and plates.

Adjacent to the berths are the workshops, furnished with all the most modern machinery for handling bars, frames, and sheets of steel—powerful punches, shears, planers, drills, hammers, presses, etc.

On account of the immense weight of the hull, the floor of the berth had to be prepared with the greatest care. First of all some 16,000 piles of timber, 13 inches square and averaging 30 to 35 feet in length, were driven down into the ground. Along the top of these were laid great beams, and on them again a complete floor of thick planks.

In the centre of the floor the shipwrights arranged the keel blocks (Fig. 42, K B) in groups of five, there being a 3-foot interval between every two groups. The cap-blocks, on which the keel actually rests, were of stout oak. A straight line drawn along the top of the blocks had a downward gradient towards the river Tyne of about half an inch in the foot, and an average distance of five feet from the ground. The reader will understand without explanation the necessity for laying the keel on the slope, in order that, when the time for launching the ship comes, the mass may be helped into the water by its own weight.

THE STRUCTURE OF A SHIP.

It is now time to say something about the actual structure of a ship, and to explain terms commonly used for the various parts. The hull of a ship is in essence a steel or iron box of curious shape. It is, in fact, a girder of the strongest kind, as it needs to be, seeing that at one moment it may be in the trough of a wave, deeply immersed fore and aft only, and the next riding on its crest with bow and stern almost out of the water. It has, too, to withstand the terrific blows of ocean billows, which tend to bend it sideways.

Putting the machinery on one side for the moment, the steelwork of a ship falls under three headings. (*a*) The skeleton; (*b*) the skin; (*c*) internal divisions. The skeleton, or framework, consists of a great backbone, the *keel* and centre girder, running from end to end, from which spring at intervals on both sides ribs, called *frames,* which curve upwards, and are connected and held together by horizontal rafters, the *beams,* carrying the decks.

There are many systems of framing a ship, each adapted for a certain purpose. The structure of a

warship differs widely in some respects from that of an Atlantic liner, and the liner in turn differs from the purely cargo boat, which must have very capacious holds. As we cannot command sufficient space for a detailed description of these various types, we will

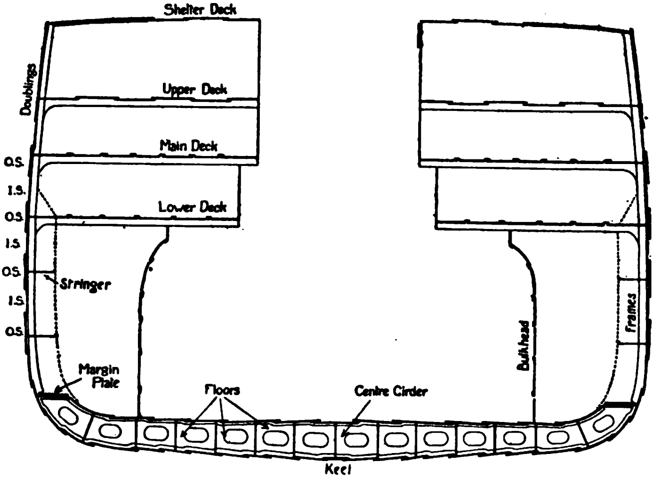


FIG. 43.—Midship section of the *Mauretania*. O S = outside strake; I S = inside strake.

confine ourselves at present to the passenger vessel, the class to which the *Mauretania* belongs.

Let us now consult Fig. 43, showing half of a midship section of our big ship. First we notice the *keel*, a flat plate 50 inches wide and 3¼ inches thick,

which runs along the centre of the vessel, and forms its lowest part. Above the keel, and also running fore and aft, is the *centre girder,* 60 inches high and 1 inch thick. On either side of the centre are seven other longitudinal girders, the outermost of which is known as the *margin plate.* These fifteen girders stiffen the bottom fore and aft, and the *floors* (which, be careful to note, are plates stood on edge) running athwart the bottom connect the girders and stiffen the bottom of the framing from side to side. The floors are riveted at their bottom edges to the *frames,* which are carried upwards beyond the margin plates to the tops of the vessel's sides, and at their upper edges to the *reverse frames.* In the middle part of the ship the floors are 32 inches apart, but towards the ends the distance decreases to 25 inches.

The bottom of the vessel is plated both above and below the floors, so as to form a number of water-tight chambers extending from the margin plate on one side to that on the other. Some of the floors are pierced with large holes, so that men may pass along the *double bottom* to examine the plates when necessary. The double bottom can be filled with water to act as ballast in lieu of a cargo, and also affords valuable protection in case of injury to the

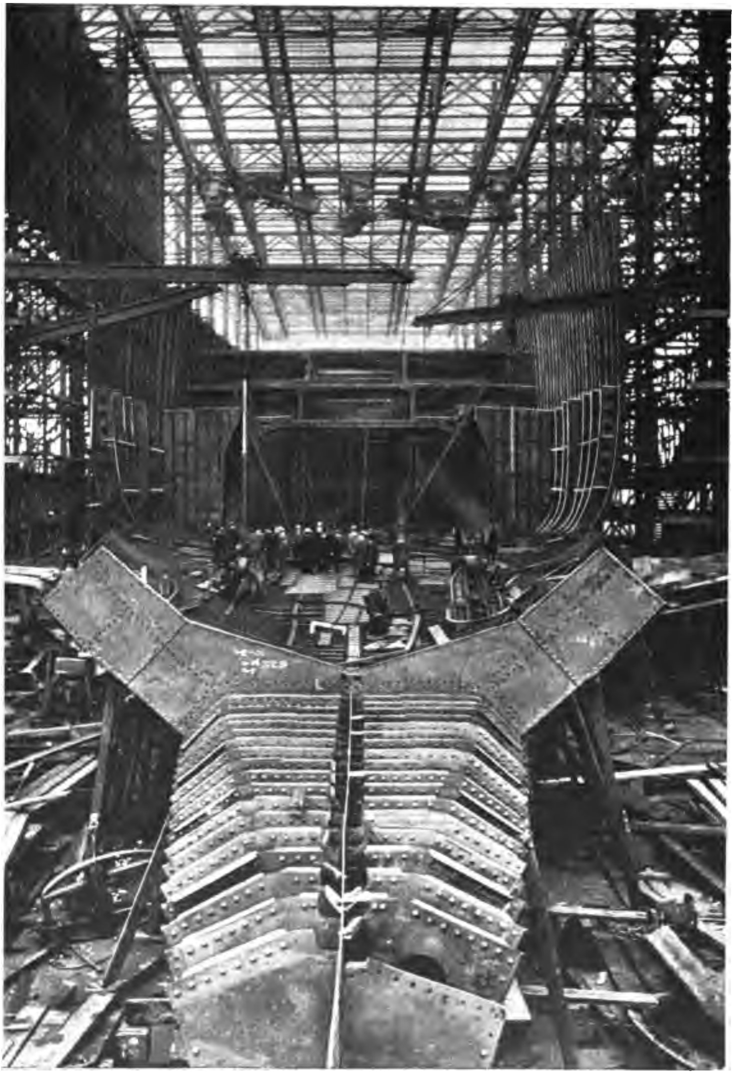


FIG. 44.—The *Mauretania* at an early stage. View looking forward from after-end of engine-room.
(Photo. "The Shipbuilder.")

outside plates. Many a vessel has been saved by her double bottom.

Above the margin plate rise the continuations of the frames, channel bars of [section, 10 inches deep. Every fourth frame is much deeper, to give additional strength to the sides. These frames are connected horizontally by the *stringers* (corresponding to the longitudinal girders of the bilge) to which are attached the *stringer plates* forming the margin of the decks, and stiffening the framework laterally, besides serving to connect the *beams* to the frames and shell plates.

The beams are supported by *pillars* and *bulkheads,* the latter being vertical watertight partitions, which divide the interior of the ship into separate chambers, as it were. If the sides of the vessel are breached the bulkhead doors are closed, and the inrush of water is confined to that compartment in which the breach occurs.

To resume: the skeleton of the vessel has longitudinal girders and stringers, connecting the cross-floors and frames, which in turn are held together laterally by the deck-beams, bulkheads, etc.

THE SKIN OF THE SHIP

is a number of steel plates of varying thickness and

size. Amidships the *Mauretania's* plating is 1 inch thick, except near the keel, where it is 1 $\frac{1}{10}$ inch thick, and at the tops of the sides, which, having to bear the heavy strains of "hogging" and "sagging," carry plates of double thickness. The diagram, Fig. 45,

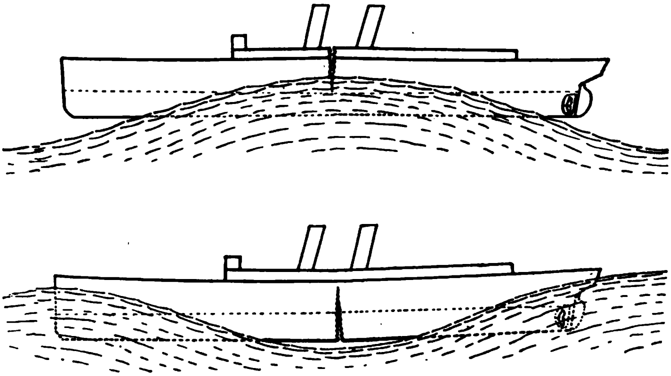


Fig. 45.—Diagrams to show "hogging" and "sagging" of a ship, and the points at which a rupture is most likely to occur.

will explain the meaning of the terms "hogging" and "sagging."

The plating is laid on the frame in *strakes,* which correspond to the courses of bricks in a wall or of boards in a wood-covered house. In Fig. 46 a strake has been marked in solid black to give the reader a clear idea of what it signifies. Each strake is composed of a number of long plates joined by their

ends. The heaviest plates of the *Mauretania* are 48 feet long and weigh from 4 to 5 tons each; the ordinary plates are 34 feet long and of 2½ to 3 tons weight.

Up the sides (see Fig. 43) every other strake is laid next to the frames. These are the "inside" strakes. The alternate, or "outside" strakes, which overlap the inside along the edges, necessarily stand away from the frames, and these gaps have to be filled up with packing-pieces. The bottom frames

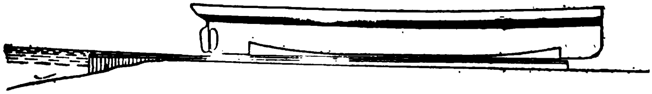


FIG. 46.—Ship in cradle. The thick black line indicates a "strake" of plating.

of the double bottom are "joggled"—that is, bent at intervals so that the plates may here be laid on *clinker* fashion, the bottom edge of each strake overlapping the top edge of that next to it on the keel side, and no packing-pieces are required for that part of the shell.

THE SHIPWRIGHTS AT WORK.

After this preliminary canter we will return to the plans of the ship. A "half-breadth" model in wood is made from the reduced scale drawings, and on it are "laid off" the sizes of the plates by lines

which show the edges and butts (the end joints) and the position of the stringer plates. Every strake is given a letter, and the plates of each strake are numbered consecutively from stem to stern. From the model are calculated the dimensions of the frames

FIG. 47.—Automobiles driving two abreast through the *Mauretania's* funnels. (*Photo, "The Shipbuilder."*)

and plates, which are entered in lists to be forwarded to the manufacturers of iron or steel. A little extra length and width is allowed to plates "in the rough," and extra length to the frames, to permit of trimming to exact size when the parts are assembled.

While the order is being executed by the steel-makers, the lines of the ship are enlarged to full size on the floor of a spacious *moulding loft,* from which the shape of the frames is transferred to the *scrive board,* a large wooden floor situated near the furnaces, made up of a large number of seasoned deals secured edge to edge by clamps.

On the scrive board will be found a full-sized body-plan (see p.), showing (*a*) the outer edges of the frames, (*b*) the upper edges of the floor plates, (*c*) the edges of the shell plates (the skin of the vessel), and other details which it is not necessary to mention. The lines are scratched deeply into the wood, and painted different colors so that they may be distinguished easily.

ASSEMBLING THE FRAMEWORK.

The keel having been laid, the centre girder is attached to it by means of angle bars, the parts having been punched with rivet holes previously. The positions of the transverse frames are then carefully marked and numbered in rotation from the stern forwards. Next follows the *bending* of the frames and reverse frames. This is effected on a *bending slab* (Fig. 48), made up of a number of

square blocks of cast-iron five inches thick, and pierced with holes in regular lines and at equal intervals. First, a strip of thin iron, called a *set-iron,* is bent on the scrive board to the exact curve of the frame. Second, the set-iron is taken to the bending slab, on which its curvature is marked with a

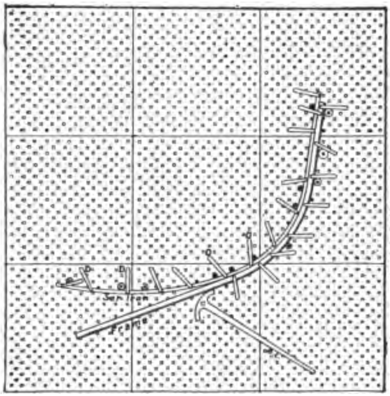


FIG. 48.—Iron slab for bending the frames of a ship. The small circles are holes. D D = dogs; B L = bending lever.

piece of chalk. Another line is drawn parallel to this, inside it, as far away as the frame is deep, and the set-iron is readjusted so as to have its outer curve on this line, allowance being made for the fact that a bent angle-bar straightens somewhat as it cools. Pins are driven into the holes in the slab nearest the inside of the set-iron, and the gaps filled up with

packing-pieces of various shapes until the iron has a firm support at the back from end to end. Third, the frame angle-bar is heated in a furnace to a bright red and taken to the slab, where it has one end pinned tightly up against the corresponding end of the set-iron, and is bent to shape by means of levers or hydraulic presses. It is held down to the slab by bent pins, called "dogs" (Fig. 48; D, D, D), driven into the slab holes.

The frames are bent in pairs, one for each side of the keel, from the same set-iron. After bending comes "proving" on the scrive board, and any necessary adjustment of shape.

Similarly with the reverse frames.

It would be wearisome to follow out in detail the fixing of the longitudinal girders, floors, and frames, and their riveting. Suffice it, therefore, to say that the utmost care has to be exercised to secure proper alignment. Every rib must be parallel to the rest, and also square to the keel, both laterally and vertically. As the keel is laid on the slope, the "plumbing" of the frames so that they shall be perpendicular to the keel is a matter of some difficulty. Measurements in all directions are constantly checked before the riveting is done and the frames fixed finally.

After the frames, the longitudinal stringers are placed in position, and the deck beams set athwartwise. The *Stem Bar,* for the bows, and the *Stern Frame,* aft, are joined on, and then* the skeleton work of the ship is ready for

FIG. 49.—First days on a battleship. Fixing the vertical keel on to the outer and inner keel to receive the bracket stays.
(*Photo, Stephen Cribb, Southsea.*)

THE PLATING.

The placing of the many plates is also a rather complicated business. The girth of the ship amidships is much greater than near the bow and stern,

* The plating of one part of a ship is often commenced before the framing is complete, in order to save time.

consequently the area of plating tapers away fore and aft, and the breadth and number of strakes must be suitably decreased.

The inside strakes are put on first. For every plate a pattern or template of thin boards is made, somewhat larger than the plate. It is clipped in place on the frames by bent irons, and on it are marked the edges of the butts (the parts which overlap, or are overlapped by, the adjacent plates in the same strake), the edges of the plate, and the position of the rivet holes in the frames to which the plate will be attached. The template is removed and clipped to the steel plate, to which the positions of the frame and rivet holes are transferred in white paint. Then the rivet holes for the edges and ends are marked, and the plate is punched, planed at the edges, and bent to the shape of the frames. Where there is much curvature special templates are made, and the bending is continued until the plate is "fair" with these.

The inside strakes having been bolted into position on the frame, the outside strake templates are prepared in like manner, and the plates marked and punched; then follows

THE RIVETING,

which is performed as far as possible with mechanical tools. As it is necessary that all outside rivets should be absolutely watertight, great attention is given to their shape and to that of the rivet holes. Every rivet is carefully inspected after being closed, and all faulty ones replaced.* The arrangement of the plate joints is not so simple as might be thought, as the overlapping joints of an inside strake do not give a flat seating for the adjacent outside strake plates. The difficulty is overcome by scarfing, or bevelling off the plates at such points, so that they may interlock.

When the riveting is completed, all the joints are *caulked,* or rendered watertight, by striking the projecting plate edge till it swells and presses tightly against the plate below. The joints are usually tested by water under pressure. This done, the plates are scraped and painted.

Simultaneously with the plating, the laying of decks and erection of bulkheads has been proceeding. The screw tubes, screws, and rudder have been placed, and innumerable jobs performed on the metalwork of the interior. The time is at hand for

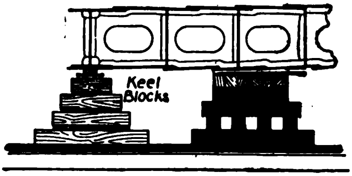
* In the *Mauretania* 4,000,000 rivets, weighing 700 tons, were used.

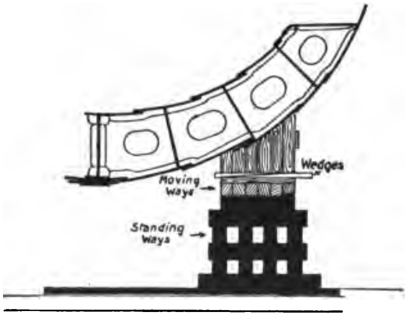
PREPARATIONS FOR THE LAUNCH,

the most critical and anxiety-causing process of ship-building. Here is the monster hull of the *Mauretania,* 16,000 tons in weight, resting on the keel blocks and the bilge blocks on either side (see Fig. 42), and shored up by a huge number of poles. The problem is to get her into the waters of the Tyne, which at this point is barely as wide as the vessel is long. The shipbuilders were careful, we may notice, to set the berths at an angle to the river, and thereby gain some extra room for the launch of vessels such as this.

Gangs of men set about preparing the *launching ways,* a huge wooden slide as long as the ship. The *standing ways* are built up on the floor of the berth, and extend some way into the water on rows of piles. The upper surfaces of these ways, which are laid strictly straight and parallel at a distance of 25 feet from centre to centre, are six feet broad. In Figs. 50 and 51 the standing ways are marked in solid black. You will notice that the outside edge of each standing way is somewhat thicker (two inches) than the rest, to form a guide for the *sliding ways* which carry the vessel.

Fore and aft, where the ship's sides are "fine" and far above the ways, *cradles* are built of large timber baulks (Figs. 52 and 53). The aft cradle grips the tubes of the inside propellers, while the timbers of the fore cradle rest at the top against





Figs. 50, 51.—Sections through launching cradles, amidships, and in way of cradle. The solid black portions are the standing-ways. Observe the wedges for raising vessel off keel blocks.

long shelf-plates attached to the sides of the ship. The cradle timbers are tied together to make a practically solid mass.

As there are no rollers in the structure, tremendous

friction would be set up between the fixed and moving ways, unless the rubbing surfaces were well lubricated, so these surfaces are smeared thickly with greasy substances shortly before the launch. For the *Mauretania* 17,150 square feet of ways had to be

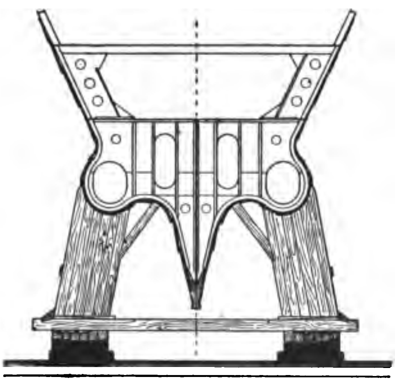


FIG. 52.—Section of after-end of cradle.

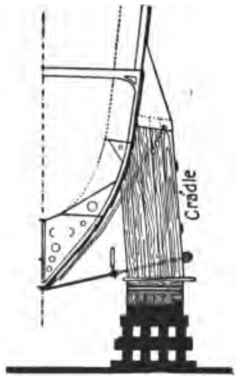


FIG. 53.—Section at fore-end of cradle. The upper ends of the cradle timbers rest against an angle plate attached to the ship's side.

(From "The Shipbuilder.")

lubricated with 14½ tons of tallow, 22 cwts. of soft soap, and 113 gallons of train oil.

In order to free the keel and bilge blocks the vessel's weight must be transferred from them to the cradles and ways. Referring to Fig. 51, you will see that between the top of the moving ways and

the bottom of the timbers next the vessel there are wedges sticking out on either side. When the time comes for freeing the blocks these are driven in, so as to force up the cradles and put the weight on the ways.

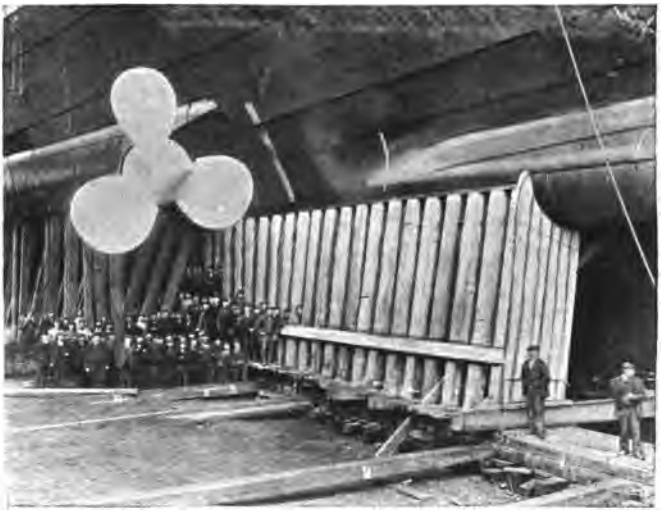


Fig. 54.—The after-cradle of the *Mauretania*. Observe the huge size of the propeller.
(Photo, supplied by "The Shipbuilder.")

It has been mentioned that the Tyne is a narrow river. Care must be taken that the stern of the ship does not strike the opposite bank, which is less than 1,200 feet from the end of the ways. In order to bring the ship up quickly after she is fairly afloat,

long cables are attached at one end to the ship and at the other to piles of chains and armor plates.

Diagram 55 shows the five 80-ton chain piles and one 100-ton plate pile on each side of the keel. The chains are laid out in squares, which have to be distorted before they will move. This prevents sudden jerks, or, to use more technical language, ensures that the load shall be taken on gradually. It is arranged that the drags shall come into action successively—

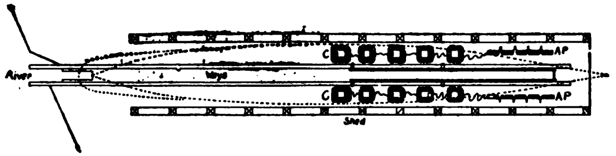


FIG. 55.—Sketch showing arrangements for launching the *Mauretania*. C C = ten 80-ton piles of chain; A P, A P = two 100-ton piles of armor plate.

the first 30 feet before the vessel leaves the ways, the last when her bows are 90 feet away in the river.

THE LAUNCH.

"All is finished! and at length
Has come the bridal day
Of beauty and of strength:
To-day the vessel shall be launched!"

The town makes holiday, and its inhabitants swell the mighty crowd of sightseers that have collected to witness the great event. Gangs of workmen, swinging huge hammers in time to a chorus, knock away the great shores, which fall one after another with a

crash, and drive in the wedges to transfer the vessel's weight from the blocks to the ways. Meanwhile hundreds of carpenters are busy under the keel, plying their trade by the light of smoking torches.

A telephone message from the yard foreman to the stand where the most illustrious sightseers are gathered tells that all is ready. A bell rings sharply, and an electric button is pressed. A moment later four hydraulic rams release the eight "triggers" which have prevented the ship moving, and the *Mauretania* begins her smooth passage to the water, slowly at first, but quickly gathering a speed of 15 miles an hour. Her stem is immersed; it floats; the water foams high before it. The wreckage of the ways and cradles covers the surface. Surely she will ground on the opposite bank! No; the trusty cables tighten, and one after another pull on the drags, the united weight of which brings her up 90 feet from the ways, within a few yards of the desired spot. Surely a triumph of calculation! From start to finish the business has occupied but seventy fateful seconds. The crowds which have held their breath in expectation now burst out into wild cheering, while fussy little tugs puff up and take the great hull off to the moorings prepared for her.

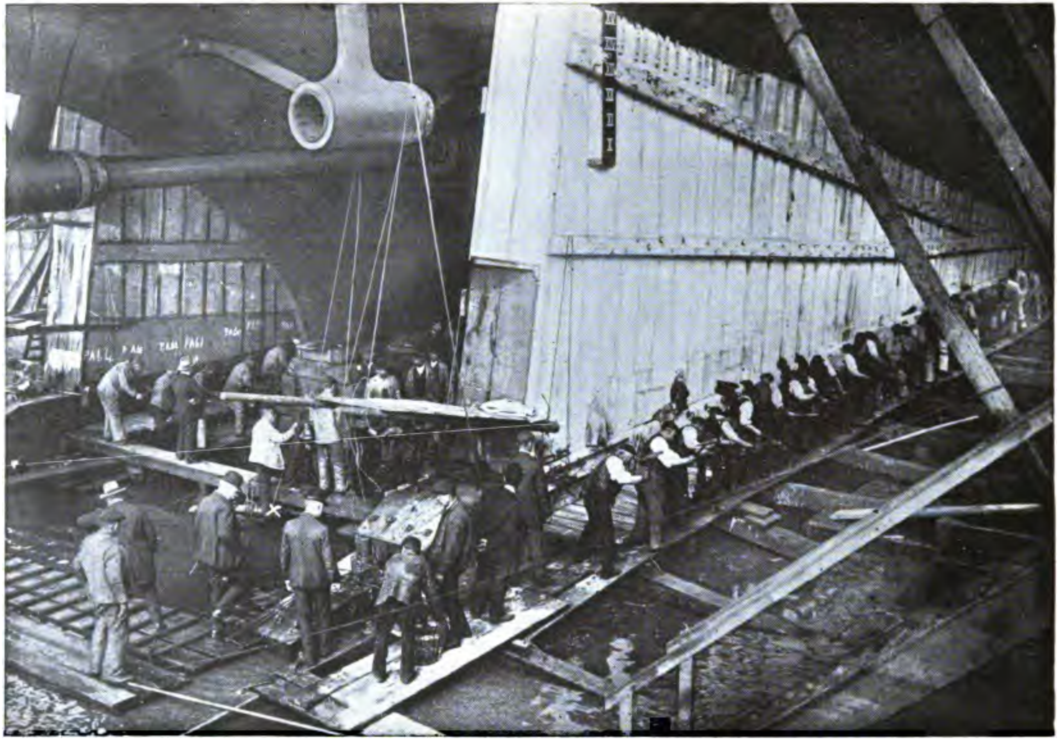


FIG. 56.—" Setting-up " a ship. Hundreds of men, armed with sledge-hammers, strike the wedges (Fig. 51) in unison, when a bell is struck. The man operating the bell is stationed at the white cross.
(*Photo, Stephen Cribb, Southsea.*)

The launch is over; the huge berth that has housed her for many long months looks astonishingly empty. The first chapter of the *Mauretania's* existence has ended happily—more happily than in the case of the transatlantic liner *Princess Yolande,* which, during its launch at Genoa in September, 1907, capsized and sank under the eyes of a large crowd.

THE ENGINES OF THE BIG SHIP.

The second chapter deals with the installation of the machinery in the hull, and the completion of its internal and external fittings. Some 15,000 tons of dead weight have yet to be added.

We will adjourn in imagination to the yards of the Wallsend Slipway and Engineering Company, where the construction of the huge turbines and boilers has been in progress simultaneously with the building of the hull. In the boiler shop, 220 feet wide and of an average length of 290 feet, stand the huge boilers, twenty-three of which contain eight furnaces each, four at either end, and two four furnaces each, making a total of 192 furnaces, which will consume many hundreds of tons of coal a day. Every boiler is 17¼ feet in diameter, and—except the last two—22 feet long. The plates used for these

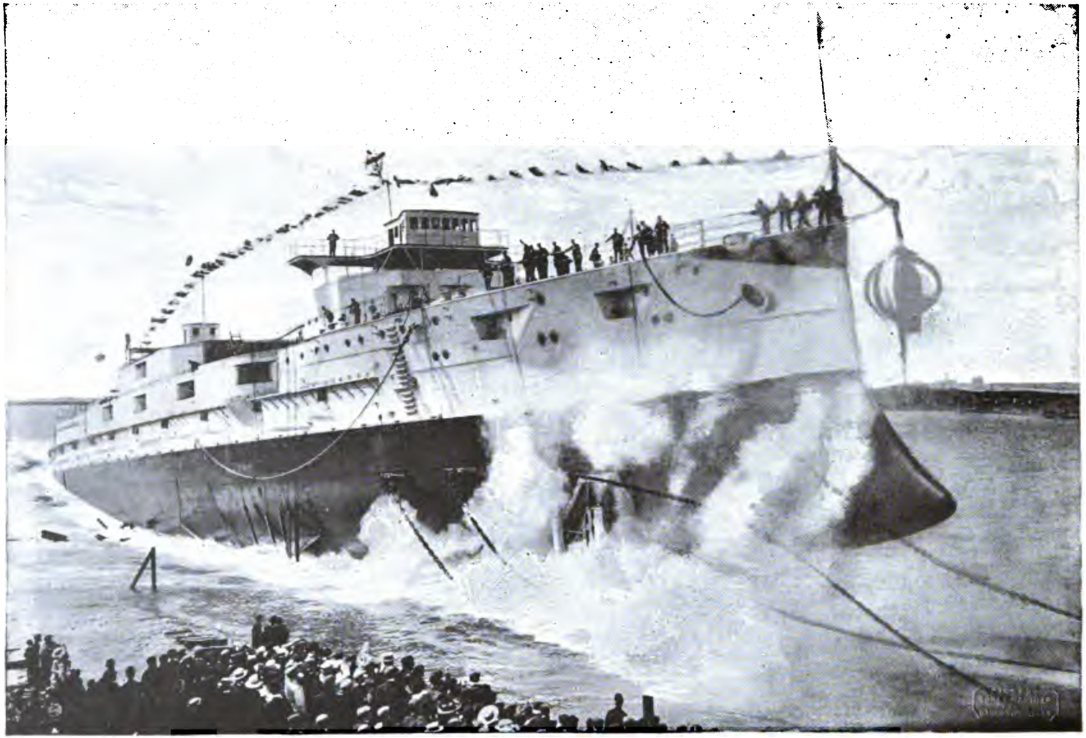


FIG. 57.—The launch of a battleship. The drag-chains and fore-cradle are prominent.
(Photo, Messrs Vickers Sons and Maxim, Barrow-in-Furness.)

great steam-raisers were of unusual size—37 feet 9 inches long, 7 feet 8 inches wide, and 1⅓ inches thick—and weighed 7 tons 3 cwt.

These monsters have been put in place by the aid of 100-ton travelling cranes running on rails overhead. Before leaving the shop we may observe a huge plate-edge planing machine, which will take a continuous strip off a plate 35½ feet long; the mammoth bending rolls for handling plates 12½ feet wide; and a hydraulic riveter with a 12-foot "gap."*

In the erecting shop we find the huge turbines—six of them: four for driving the ship forward, two to take her astern.

Now for a short description of these. The sizes of the rotors, or revolving parts of the turbines, are as follows: The high-pressure (which receive the steam direct from the boilers) are 96 inches in diameter, have blades ranging from 2½ to 12 inches in length, and weigh 72 tons each with the shaft. The low-pressure (which take steam from the high-pressure) are 140 inches in diameter, have blades 8 to 22 inches long, and weigh 126 tons each. The astern (also high-pressure) are 104 inches in diam-

* That is, one having arms long enough to close a rivet in a hole 12 feet from the edge of a plate.

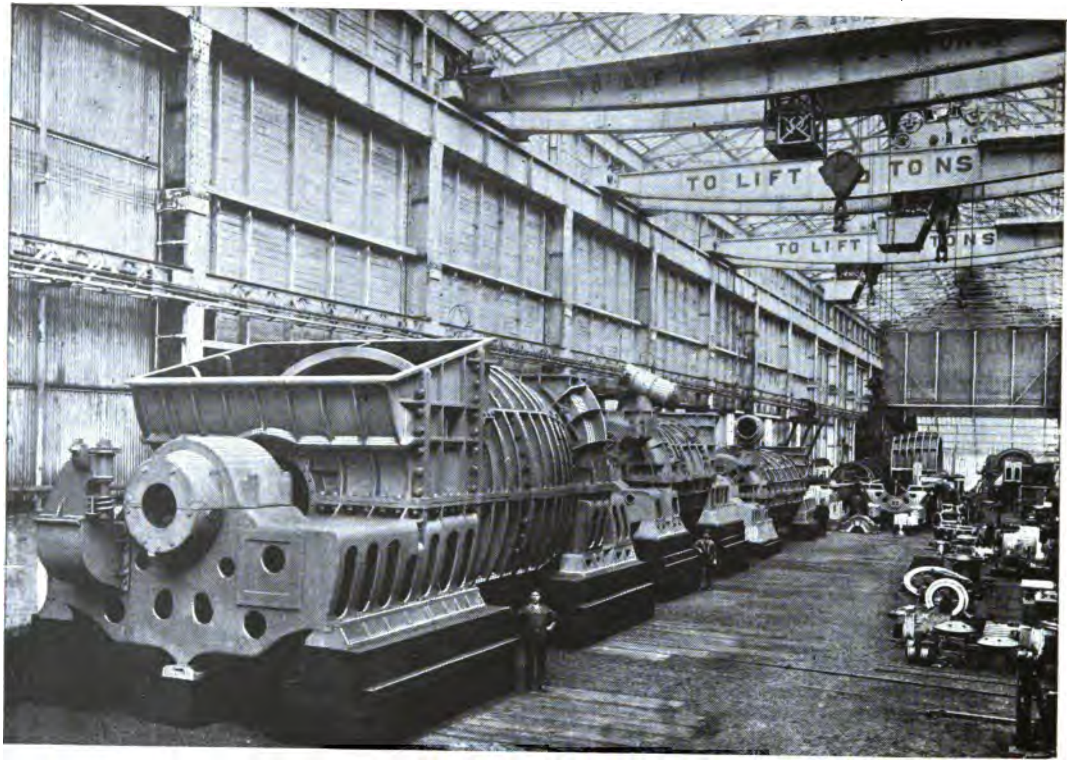


FIG. 58.—One of the four sets of turbines for the *Mauretania*.
(Photo, The Wallsend Slipway and Engineering Co.)

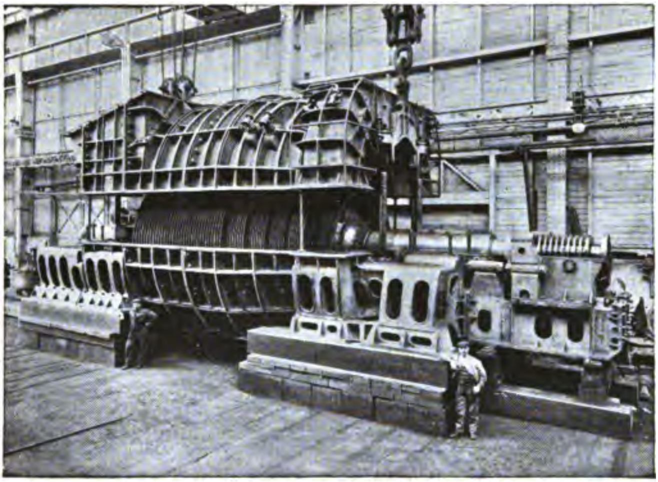


Fig. 59.—Low-pressure turbine, showing top half of casing lifted.
(Photo, The Wallsend Slipway and Engineering Co.)

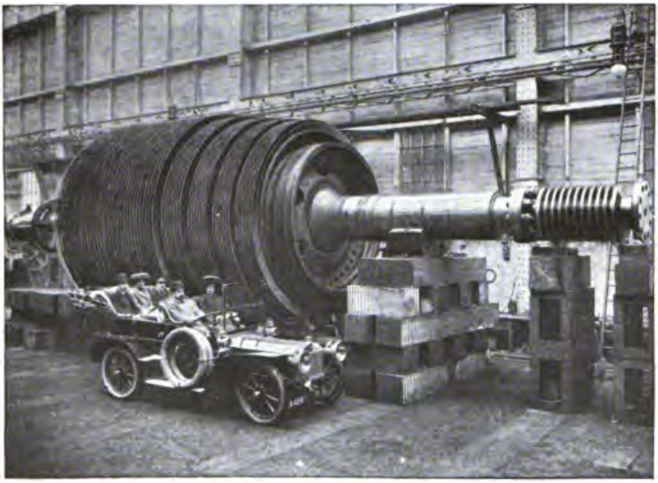


Fig. 60.—Low-pressure turbine rotor, fully bladed.
(Photo, "The Shipbuilder.")

eter; their blades range from 2 to 8 inches in length; weight, 60 tons. The drum of each of the high- and low-pressure rotors is compounded of three great rings, lathed inside and out, screwed and shrunk together. The astern drums are made up of two rings only.

As for the turbine casings, their lengths "over all" are 45 feet 8 inches, 48 feet 2 inches, and 30 feet 1¼ inches for the high-pressure, low-pressure, and astern turbines, respectively. The casings were compounded of six castings each, three for the top half and three for the bottom, each casting being carefully machined so as to make a perfect fit with its neighbors.

The shafts are 3 feet in diameter for the high-pressure, 4 feet 4 inches for the low-pressure, and 3 feet 3 inches for the astern turbines, and all hollow.

The blades, of which there are many thousands in each turbine, were built up in segments (Fig. 61), ten of which made a complete ring (Fig. 62). The foundation of each segment is a slotted curved bar, which, when the blades are all in position, is fixed into an annular groove in the drum by means of strips of metal driven tightly in between it and the sides of the groove. This method of blading was found to be very much more expeditious than the

Fig. 61.—A segment of blading for turbine rotor.
(Photo, The Wallsend Slipway and Engineering Co.)

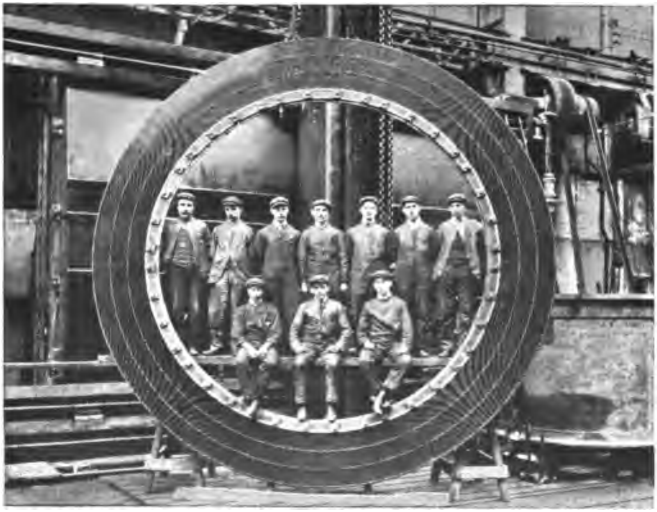


Fig. 62.—Complete circle of blading for rotor.
(Photo, "The Shipbuilder.")

older system of keying the blades directly into the drum. The rings of fixed blades, which alternate with the rotor rings, were attached to the inside of the casing in a similar way.*

FITTING OUT THE SHIP.

A huge 150-ton floating crane transferred the boiler, turbines, and other machinery from the makers' yards—the parts of the turbines being of course separated for the process—into the lowest depths of the vessel, below the water-line. As they arrived they were assembled and made fast in place. Gangs of fitters supplied the boilers with their numerous fittings, and connected them up to the turbines, which in turn had their shafts bolted on to the propeller shafts. Then the huge "uptakes" to lead the furnace gases to the funnels were installed, and on the top of these the funnels themselves, four in number, one for each boiler-room. The funnels measure 23 feet 7 inches from back to front, and are 16 feet 7 inches wide—are so gigantic, in fact, that while they lay in the builders' yard motor cars were driven two abreast through them (Fig. 47). Their tops are 153 feet above the keel of the ship.

* For a concise explanation of the working principle of the Parsons' steam turbine, see "How It Works," p. 79 and following.

After these, the auxiliary machinery of divers kinds—steering engines, pumps, draught and ventilating fans, evaporators, heaters, cranes, boat-hoists, fire-engines, dynamos. In the passenger quarters carpenters, polishers, painters, plumbers, glaziers, upholsterers, electricians, and other craftsmen were hard at work furnishing the hitherto empty spaces of the hull with the fitments of an ultra-luxurious hotel, down to a complete telephone installation with a capacity for two hundred stations and twenty exchange lines. The very clocks are of the most modern type, the forty-five distributed over the ship being worked electrically from a centrally-placed master-clock, which, it is hardly needful to state, is kept strictly to time.

In the kitchens are ranges with a total frontage of 70 feet, and manifold labor-saving appliances. The bakers' and confectioners' shops contain all the apparatus that any reasonable maker of bread and pastry could possibly desire. Among the contents of the pantries are 3,000 pieces of "hollow ware"—dishes, tea and coffee pots, tureens, etc.—and 16,000 spoons and forks—a huge number indeed, but none too large for the maximum population of this ocean leviathan.

The splendid lifts to transport passengers from deck to deck; the gorgeous saloons and dining-rooms; the princely suites of staterooms; the gymnasium; the children's nurseries—on these and a host of other notable features we should like to dilate, but space

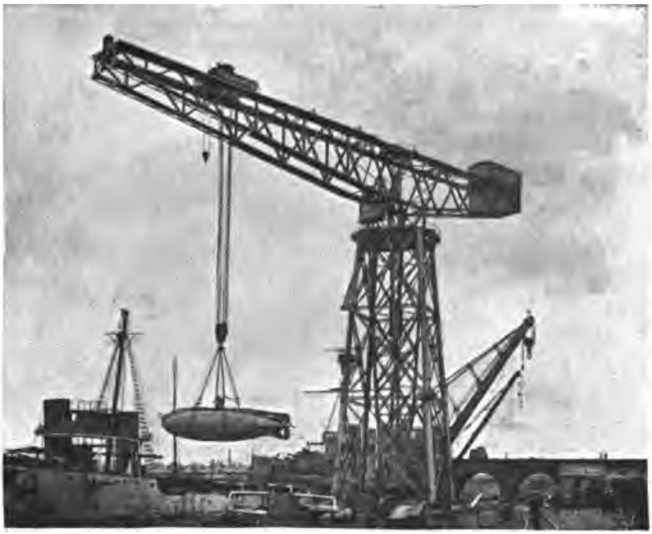


Fig. 63.—A 150-ton crane lifting a submarine.
(Photo, Messrs. Vickers Sons and Maxim.)

forbids. We must hie us back to the engineering aspect of the *Mauretania*.

When the vessel has all its machinery in place and connected up, steam is raised and the engines are given a *dock trial* for twenty-four to forty-eight hours,

the ship being made fast to the wharf so that she cannot move. During this trial the action of all parts of the machinery is carefully watched, records are taken, and any defects are put right.

Then comes a trial in the open sea, to see how she behaves when "allowed to rip," what the speed is, and how much fuel she burns to produce it. The next item on the programme is to dry-dock her, and clean and paint the bottom, to prepare her for

THE OFFICIAL TRIALS

of forty-eight hours under full pressure. When so large a boat as the *Mauretania* has to prove herself, public interest is stimulated, and the results of the trial eagerly awaited. The *Mauretania's* trial took place between Corsewall Point in Scotland and Land's End in Cornwall, a distance of 300 knots, two southerly and two northerly trips being made. The results exceeded all expectations, and broke all previous merchant-ship records handsomely. The average speeds of the four runs were as follows:—

	KNOTS.
First run, Corsewall Point to Land's End	26.28
Second run, Land's End to Corsewall Point	25.26
Third run, Corsewall Point to Land's End	27.36
Fourth run, Land's End to Corsewall Point	25.26
Average speed throughout	26.04

The third run was an extraordinary performance, with its average speed of 31¾ miles an hour for 300 knots, and this attained, not by a slim, snaky torpedo destroyer, but by a floating mass displacing 36,000 tons of water!

Years ago Ruskin wrote that a ship of the line was the most honorable thing that man, as a gregarious animal, had ever made. To use his own words: "Into that he has put as much of his human patience, common sense, forethought, experimental philosophy, self-control, habits of order and obedience, thoroughly-wrought handiwork, defiance of brute elements, careless courage, careful patriotism, and calm expectation of the judgment of God, as can well be put into a space 300 feet long by 80 feet broad." If the ship of his time stirred him to such enthusiasm, what, we wonder, would he have said of the vast merchant-ships and monster warships of to-day, filled from stem to stern with the most complex machinery, and capable of speeds which dwarf those of a few decades ago?

Chapter IV.

BRIDGE BUILDING.

Bridge *versus* tunnel—The development of the bridge—Plank bridge—The open-work girder or truss—The bowstring girder—The arch—The suspension bridge—The cantilever principle—Development of same—Advantages of the cantilever.

WHEN a road or a railway has to be carried from one bank of a river to the other, the engineer must choose between a tunnel and a bridge. In ninety-nine cases out of a hundred the bridge is selected without hesitation; but in the remaining one case the engineers may have to make long calculations of cost, and set one thing against another, and generally think the question out very carefully before they can come to a decision. In several of the great cities of the world through which an important river flows—New York and London are conspicuous examples—both bridges and tunnels are used, as at one point a bridge may be constructed more economically than a tunnel, and at another point natural conditions may favor the

tunnel. The Niagara and Zambesi gorges, with sides precipitous and not very far apart, are eminently suited to bridgework, and a tunnel would here be quite out of the question. But at certain places on the Thames, where the banks are low, a tunnel "fills the bill" better than a ship-impeding bridge.

Big bridges afford such splendid examples of the engineer's skill that you will like to know how they are built. Those tall, upstanding towers, massive piers, huge cables, far-reaching girders, gigantic arches, whan an infinity of labor they represent! Well may you admire the patient scheming and dogged struggle which went to their making.

THE DEVELOPMENT OF THE BRIDGE.

Let us begin at the beginnning—that is, with the simplest forms of bridge, and trace its development into the great structures of masonry and steel which span our rivers.

Fig. 64 is a type which we know very well—a stout plank thrown across a ditch. As you walk over it it bends distinctly, and you don't like any one else to step on until you have reached the other end. Such a bridge would not stand heavy loads. But set a couple of such planks on edge joist-wise, as in Fig.

65, and lay short planks across them, and you have a bridge over which a horse and cart might pass safely, because long flat bodies of wood, metal, or other hard

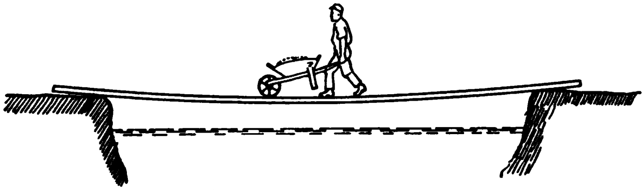


FIG. 64.—A plank bridge.

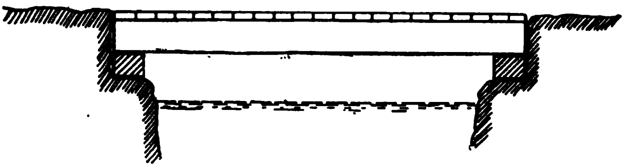


FIG. 65.—Bridge of planks laid joistwise, and covered with cross-pieces.

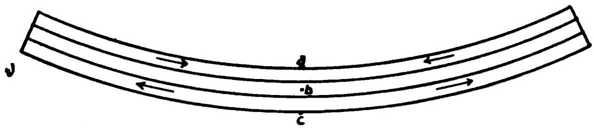


FIG. 66.—Diagram to show strain in a bent plank.

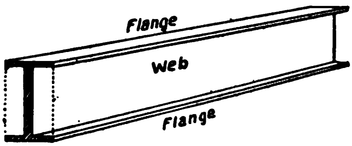


FIG. 67.—A steel girder.

substances will stand a much greater strain joist-wise than plank-wise. The reason for this is shown in Fig. 66, which represents a bent plank. Only the

middle part, *b*, retains its original length. The upper edge is shortened and the lower edge lengthened by bending; and the further *a* and *c* are from *b* the greater will be the resistance of the plank to bending. A plank 6 inches by 1 inch in section set on edge would stand a greater weight than two planks 3 inches by 1 inch, and these in turn would be much stronger than six battens 1 inch square. It must be remembered, however, that our plank loses in rigidity in one direction as it gains rigidity in another, assuming its bulk to remain unaltered. The wider it is the thinner it must be. Now look at Fig. 67, which represents a piece of I-section steel bar. The flat, broad edges give it lateral strength, while the deep, upright part makes it very strong vertically. An ordinary railway rail is a girder of this type. Notice before passing on that the top and bottom edges of such a girder are named *flanges*, the central upright part the *web*.

For spans of 125 feet or less a solid built-up plate girder of type Fig. 67 is used. When that length is exceeded the solid is replaced by

THE OPEN-WORK GIRDER OR TRUSS,

built up of plates and bars. This is stronger in pro-

portion to its weight than is a solid-web girder, because all superfluous metal is excluded, and what is used is so disposed as to give the best results.

The truss derives its strength from the fact that three bars joined together to form a triangle resist distortion. Let us consider Fig. 68 for a moment.

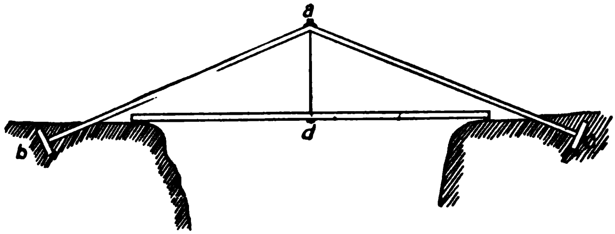


FIG. 68.—Plank supported by inclined struts.

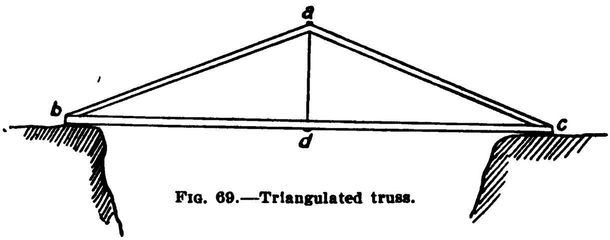


FIG. 69.—Triangulated truss.

This shows a plank suspended by a bar *a d* from two inclined beams *a b, a c* meeting over its centre, their lower ends resting on the ground.

If the plank be loaded the stress will be thrown on to the struts *a b, a c,* which cannot be pulled down without spreading their lower ends. Consequently,

if the ends be firmly supported, this simple bridge will carry a heavy weight. The same stiffness is obtained in a somewhat simpler manner by joining planks and struts, as in Fig. 69, to form a triangle

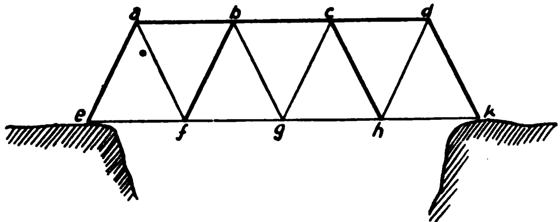


FIG. 70.—Compound triangulated truss. Member in compression denoted by thick lines.

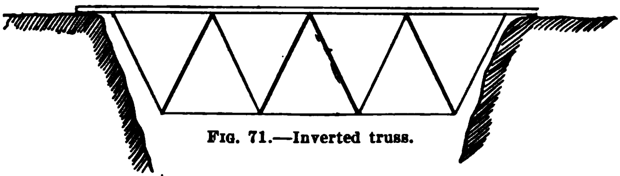


FIG. 71.—Inverted truss.

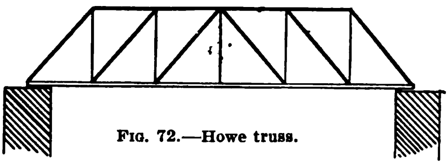


FIG. 72.—Howe truss.

a b c. Next we join several triangles together (Fig. 70). A weight suspended from the middle would tend to bend the lower chord, *e f g h k,* and bring the apices of the triangles nearer to the central vertical line. This is prevented by the stout upper chord,

a b c d. The bars or beams that are in compression are marked thick, those in tension thin. Fig. 71 shows the girder turned upside down. The positions of the tension and compression members, as they are called, are reversed, *a b c d* being now in tension and *e f g h k* in compression.

Before going further we must observe that the horizontal upper and lower parts of a truss are called *chords;* the vertical braces, *posts;* the sloping braces which have to withstand compression, *struts;* and braces in tension, *ties.*

Fig. 72 is another form of the truss compounded of triangles, and in Fig. 73 we see a combination of the preceding two.

The *Bowstring Girder* (Fig. 74) is another form of truss, having a curved compression chord and a straight tension chord. Sometimes a "bowstring" is incorporated with a lattice girder of the type shown in Fig. 73.

THE ARCH

(Fig. 75) also contains a curved compression chord, but, unlike the truss, it has no tension chord, the latter being replaced by the resistance offered by the abutments against which the ends of the arch press.

At Niagara may be seen a very fine instance of the arch bridge.

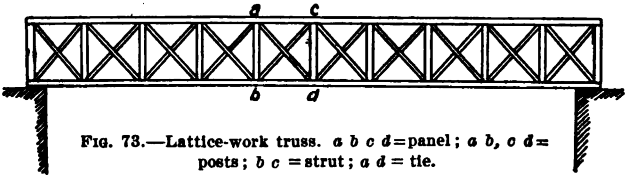


Fig. 73.—Lattice-work truss. *a b c d*=panel; *a b*, *c d*= posts; *b c* =strut; *a d* = tie.

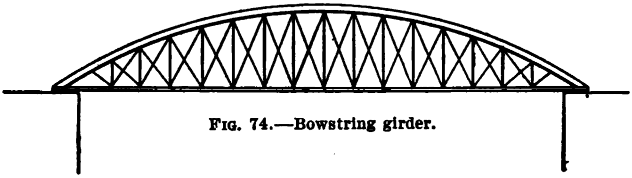


Fig. 74.—Bowstring girder.

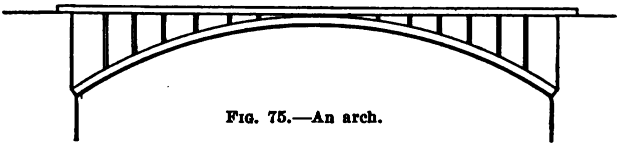


Fig. 75.—An arch.

For spans exceeding 600 feet the arch or truss supported at the ends only is seldom used.

Some of the longest spans in the world—1,500 feet and more—are found in

THE SUSPENSION BRIDGE.

Fig. 76 is a very crude bridge of this kind—just a couple of ropes slung across a gorge and transverse bars laid on them. It has little stability, its curves

changing as the load moves, and on account of its "dip," which has to be considerable to relieve the strain on the cables, is not suited for heavy traffic.

Fig. 77 is a suspension of a more scientific design. A level roadway is suspended by ties fróm the cables, which are attached to anchorages at a higher level.

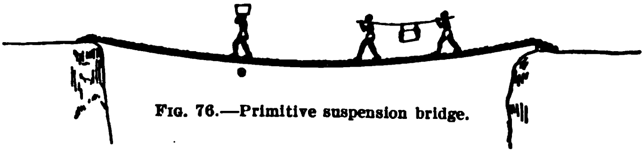


FIG. 76.—Primitive suspension bridge.

FIG. 77.—Improved suspension bridge.

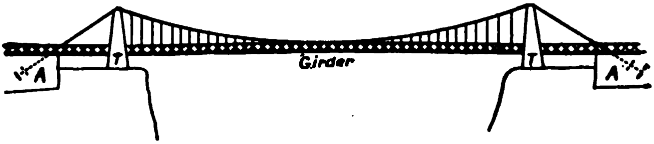


FIG. 78.—Steel suspension bridge. A A = anchorages; T T = towers, or supports.

And then we pass on to Fig. 78 and the modern engineer's suspension bridge. On or near each bank of the river to be spanned is built a high tower, T, and a massive anchorage, A. Cables or chains are passed over the towers and anchored at each end, drooping between the towers to the level of the roadway, which

runs on a continuous *stiffening girder* having a slight "camber" or rise towards the centre. Vertical and sometimes diagonal ties join the girder to the cables at regular intervals from end to end so as to distribute the weight of the girder and its moving load over the cables as equally as possible.

The suspension is practically a one-span bridge.* When the distance is too great for a single suspension span, and the points on which piers can be built to carry trusses are very far apart, recourse is had to the

CANTILEVER PRINCIPLE.

If you turn up the word "cantilever" in Webster's dictionary you will find that it signifies "a projecting beam, truss, or bridge unsupported at the outer end; one which overhangs."

Once again let us trace development. Fig. 79 shows two beams or cantilevers, *a* and *b*, with one end fixed firmly down and the other ends projecting into space. A third beam, *c*, laid across the gap, completes the bridge.

The Chinese made use of the principle hundreds of years ago. Fig. 81 is a sketch of a very old Chinese

* It sometimes has two shorter "shore" spans between the towers and the anchorages.

cantilever bridge. First the beams *a a* were placed, then the longer beams *b b,* then the still longer beams

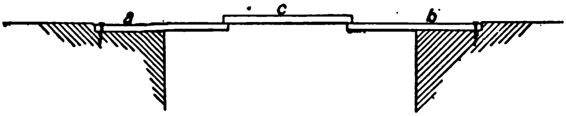


FIG. 79.—Diagram to illustrate the principles of the cantilever bridge.

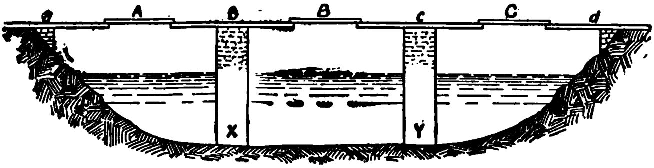


FIG. 80.—Cantilever bridge of three spans.

c c, and finally *d d,* which reduce the gap sufficiently for a short girder *e* to span it.

FIG. 81.—Chinese cantilever bridge.

Fig. 80 represents diagrammatically a more elaborate system. The end cantilevers, *a* and *d,* are fixed, as in the first instance; the other four are in pairs,

b and *c,* supported at the middle on the piers X and Y. Three "suspended girders," A, B, and C, bridge the gaps.

In Fig. 82 we have the fully developed type, illustrated in the Forth Bridge, the cantilevers of which are very deep trusses of a somewhat triangular shape arranged in pairs, with their bases formed by

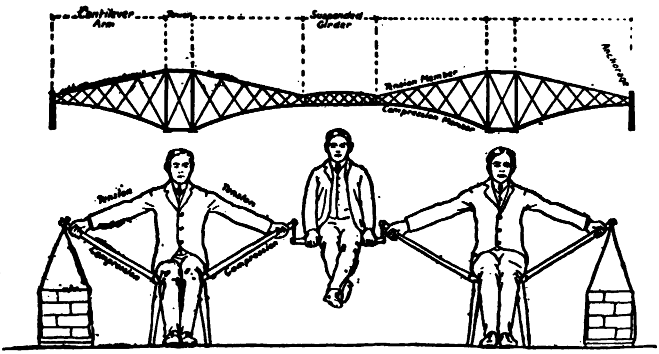


FIG. 82.—The cantilever principle elaborated.

the side columns of lofty steel towers. The figures below correspond to the parts of the diagram immediately above. Chairs represent the piers on which the towers are built, and the two boys sitting on them the towers themselves. Each boy extends his arms and supports them by stout sticks resting against the seats of the chairs. From the ends of the inside

sticks is hung a board, to illustrate the suspended girder, whereon is perched a third boy. His two supporters are prevented from toppling over inwards by having the ends of the outside sticks attached to piles of bricks as anchorages. The series of cantilevers might be extended indefinitely provided anchorages formed the terminals.

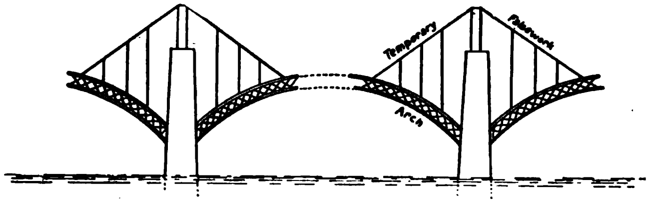


FIG. 83.—Arches built out on the cantilever principle.

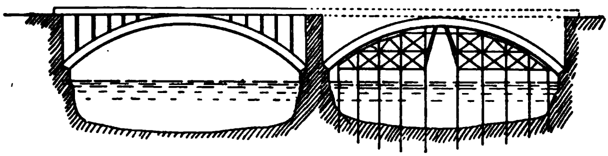


FIG. 84.—Arches supported by "falsework" during erection.

The great advantage of the cantilever system is, that the cantilever arms can be built out in pairs on either side of their towers, so as to balance one another during construction and be quite independent of external support. The *principle* is employed even in the erection of some bridges which when finished do not represent the cantilever type. Thus, the St.

9

Louis Bridge, with three arched spans of over 500 feet each, was built out on the balance principle (see Fig. 83) until the halves of the arches met. The ties suspending them from the temporary works built on the top of the piers were then removed. The usual plan of steel arch erection is shown in Fig. 84. "Falsework" is erected on piles driven into the river bed to give support to the steelwork till it is able to support itself, just as wooden "centres" are used for masonry arches.

Chapter V.

THE FOUNDATIONS OF A BRIDGE.

Need for firm foundations—Three methods of obtaining them—The pneumatic caisson—Its use for the Forth Bridge piers—Sinking a caisson—The ejector—The hydraulic spade—Filling in a caisson with concrete—Blasting—Deep work with the pneumatic caisson—"Caisson disease"—The deep, open caisson—Cofferdams—Pile-driving.

WHATEVER be its type—truss, suspension, cantilever, or arch—a bridge must stand on absolutely secure foundations, which shall not budge the fraction of an inch; and in the case of a very large bridge that portion of it which is below water or earth level, and out of sight and mind, often represents the larger part of the total difficulties and expense entailed in the construction of the whole.

If the engineer finds rock ready for him, well and good, for rock is the best of all foundations. But it happens frequently that he is called upon to obtain a firm footing for a pier on the soft banks or in the treacherous bed of a river. He must delve down

through silt, clay, and quicksand, until he reaches a stratum sufficiently firm to suit his purpose.

Generally speaking, there are three principal methods of sinking foundations in a river bed or through water-logged strata. The first employs the *pneumatic caisson,* a huge diving-bell in principle; the second, the *deep, open caisson;* the third, the *cofferdam.*

To take these in order,—

THE PNEUMATIC CAISSON

is a cylinder or coffer of steel or wood, closed at the top but open at the bottom, which carries a steel cutting edge. The caisson is loaded so as to sink by its own weight, while men working inside, under an air pressure sufficient to prevent water entering beneath the cutting edge, excavate the bed and send the "spoil" up through air-locks, or, if the material be liquid enough, eject it through pipes.

As a good instance of work of this kind we may take the sinking of the cylindrical pneumatic caissons on which two of the three huge towers of the Forth Bridge rest. A section of one of these caissons is given in Fig. 85. Built of steel plates, they somewhat resemble gasholders in external appearance.

They had a diameter of 70 feet at the bottom, but tapered to about 60 feet at the top. Seven feet above the bottom edge an air-tight floor was formed,

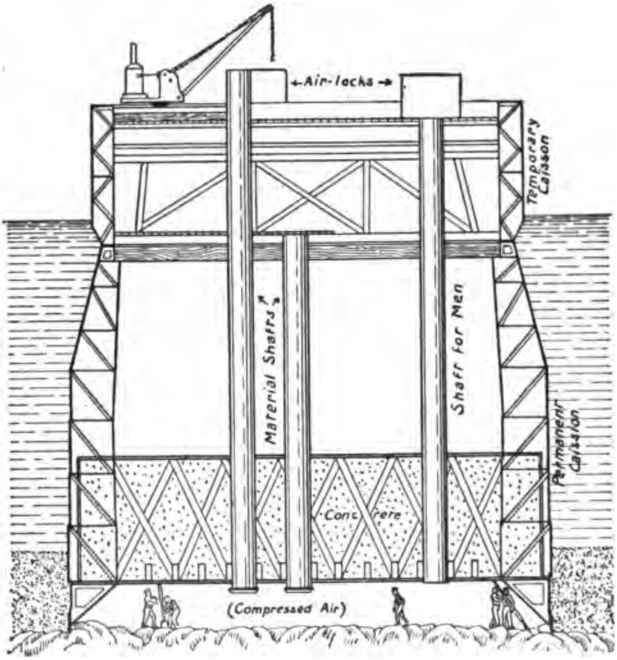


FIG. 85.—Section of one of the pneumatic caissons used for building the piers of the Forth Bridge.

extending over the whole area up to the outer shell, and supported from above by four strong lattice girders reaching from side to side. Above the floor the caisson had an inner shell, concentric with the

outer, to which it was stayed. On the top of each caisson the engineers erected a temporary extension of the sides to exclude water at high tides, and inside were built platforms for cranes, air-compressors, mortar-mixers, etc. Three shafts—two for materials, one for men—each furnished with an air lock (Fig. 86), connected the bottom chamber with the platforms.

FIG. 86.—Sections of air-lock.

When complete, the caisson was launched and towed to the spot where it was to sink on to a bed previously prepared by divers. The roof of the air-chamber was then loaded with sufficient concrete to make the caisson settle and just prevent it floating at high tide. Pipes leading into the air-chamber through the floor above, and terminating in flexible nozzles, were then set to work to clear out the semi-fluid silt which formed the top of the river bed. A hollow having been dug in the ground, water was allowed to flow into it and mix with the more solid material until the proper consistency for ejection had

been obtained. The man working the ejector then dipped the end of his bore into the sump till it was almost submerged. The high-pressure air of the chamber rushed up the tube with great velocity, carried with it some of the mixture, and expelled it in gulps. In this way the soft surface was stripped off. On reaching clay the ejector could be used for removing water only, and the men had to do genuine navvy-work, with spades and picks, loading the loosened materials into buckets running up and down the shafts. When hard boulder clay was struck, dynamite and powder were resorted to, but with little effect, as clay has no "grain," and is too yielding for explosives to rend it as they would harder substances. To dig out this clay by hand proving impracticable, Mr. Arrol, the contractor for the bridge, devised a *hydraulic spade,* with a large, wide blade which a ram resting against the top of the chamber, drove deep down into the clay. This machine detached slab after slab, and gradually ate its way all over the area covered by the caisson. It was then arranged to undercut the edge, pillars of material being left at intervals to support the caisson at points all around the circumference, until the bearing surface could no longer sustain the

weight, and the caisson gradually cut its way down through the pillars. Then the process was repeated, and the concrete load above the floor augmented to overcome the increased resistance of the clay.

Great care had to be taken to ensure the caisson sinking on an even keel and in the correct perpendicular line. From day to day it would tilt a little this way or that, and any tilt had to be rectified at once by undercutting at the opposite side of the diameter. At low tide, when the buoyancy of the caisson was least, and the danger of a sudden settlement greatest, the men were usually withdrawn; and wisely so, for on one occasion a caisson sank 7 feet, completely filling the air-chamber and part of the shafts.

The greatest depth reached by one of these hydraulic caissons was 89 feet below high-water level. The sinking occupied on an average about three months, and the amount of material excavated under each caisson was about 6,500 cubic yards.

When a caisson had reached its final position, the chamber was cleared ready for filling with concrete. As it was necessary to maintain a high air-pressure to keep water out, and yet to send the concrete down quickly, the engineers removed the air-locks from the top of the material shafts, and fixed inside the shafts

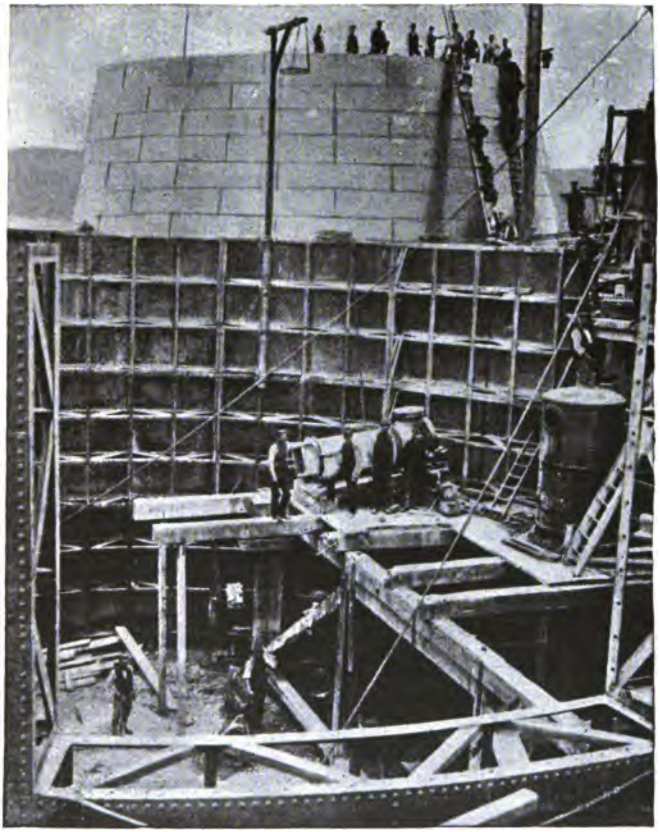


FIG. 87.—Construction of temporary caisson, Forth Bridge. In the background is seen a complete caisson.

18-inch tubes reaching from the air-chambers to the platform on the caisson top, where the concrete-mixers were installed. Each tube had a flap top and

bottom. To pass down a charge of concrete the following operations were performed. First, the men down below closed the bottom flap tightly, and sent up a signal that it had been closed. The workmen on the top then opened their flap, shovelled in concrete until the tube was nearly full, and closed the flap again. A signal having been passed down, the air-chamber gang turned a valve to admit compressed air into the tube above the concrete, and opened the lower flap. Out came the load with a rush, to be spread round the edges of the chamber. In course of time the space was filled completely, and after it the shafts. Finally, liquid cement was run in to occupy any existing cracks and crannies that the workmen had not been able to reach, and this part of the business was finished. It remained to fill in the space above the chamber to low-water level with concrete, and to lay on the concrete the granite courses forming the top of the pier. As the weight of each tower of the bridge is distributed among four piers, there is very little danger of any settlement occurring.

For some of the Forth Bridge piers a resting-place had to be cut in solid rock, below water. The workmen drilled holes by hand or with power drills, inserted the explosive charges, connected them up with

wires leading to an electric battery outside the caisson, and withdrew. The closing of the circuit fired all the charges; and the chamber was cleared of the foul gases of the blast by forcing in a surplus quantity of air to drive the gases out under the cutting edges of the caisson.

The same principle of the diving-bell has been used for the foundation of many famous bridges. The most notable feat of deep sinking under pressure must be placed to the credit of the men who built the piers of the great arch bridge that spans the Mississippi at St. Louis. Owing to the shifting and unsatisfactory character of the river bed, the engineer, Captain J. B. Eads, decided that it was necessary to get down to the rock; and down to rock he sent the great caissons, though it meant that the excavators had to descend 110 feet below water level and work under an air-pressure of about 50 lbs. to the square inch.

Labor at these great depths is far from pleasant. The large supply of oxygen enables men to work with unusual, though exhausting, energy; but only the physically strong can stand the strain for any length of time. Owing to the density of the air, voices sound harsh and metallic, robbed of all the small

inflections that would differentiate them in the open. Noises are exaggerated tenfold; what would be but a tap elsewhere has the sound of a heavy blow. Then there is a "caisson disease"—that scourge of folk who labor in high air-pressures. Its symptoms are severe pains at the joints when the air pressure is reduced to normal, and relief is obtained only by restoring the pressure. Investigations have traced the trouble to excessive absorption of nitrogen by the blood. In their hurry to regain the upper air, workmen are impatient of using the air-locks to decrease the pressure gradually enough to allow the excess of nitrogen to be expelled through the lungs. The result is that the gas, suddenly released, forms bubbles, which obstruct the flow of blood in the minute veins, and great local inflammation arises. Some Forth Bridge excavators were, we read, so punished by the malady that they would voluntarily spend their holidays and Sundays in the caissons, to ease their swollen joints. Where proper care is used, "caisson disease" is kept at bay, and in some works a gradual release from pressure is enforced.

THE DEEP OPEN CAISSON

is used for sinking to depths which would be unat-

tainable by the pneumatic system. The caisson is usually divided by vertical partitions into tall, chimney-like chambers, all open at the top. Some of these chambers are closed at the bottom by sloping floors, terminating in a cutting edge (Fig. 88), and are filled up with heavy materials to give the structure sufficient weight; the others serve as shafts for mechanical dredges which scoop away the ground from the surfaces surrounded by the cutting edges. By means of open caissons foundations have been carried to a depth of 175 feet below water level—a truly remarkable feat, considering that the actual excavation is done by machines under the control of men a hundred feet or more above the surface attacked, who have to

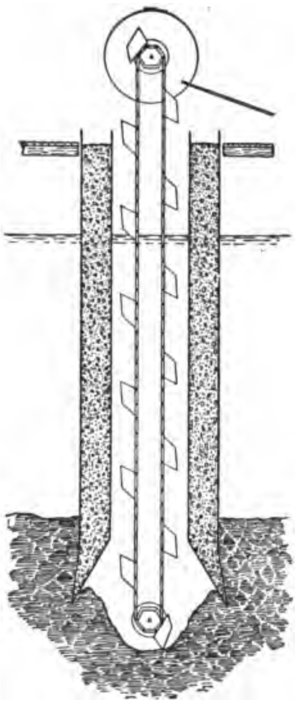


FIG. 88.—Sinking deep open caisson by means of bucket-dredge operated from above the water-line. The shaded portions are chambers loaded with stones or concrete to force the cutting-edges downwards as excavation proceeds.

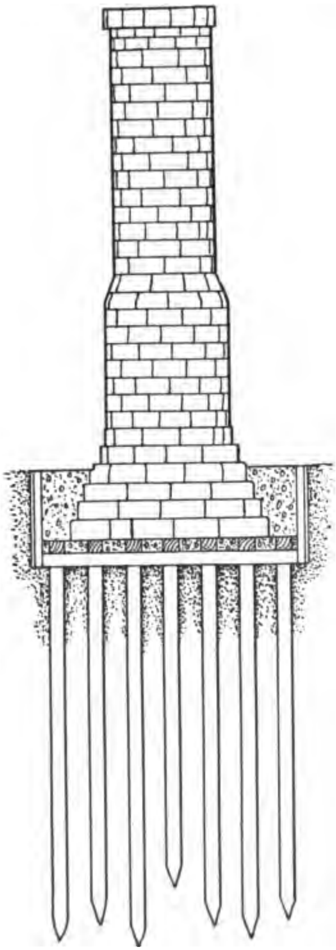


FIG. 89.—A masonry pier resting on piles.

operate the dredges in such a manner that the caisson, weighing perhaps several hundred tons, shall sink quite vertically.

When the caisson has reached the required depth the dredges are removed, and the open chambers are filled up with concrete, whereon the masonry of the pier is raised.

COFFERDAMS

are used where a good bearing material is found at a moderate depth. A cofferdam is generally constructed by driving a ring of piles in contact with one another round the area on which the foundations are to be

built, forming a second ring outside and parallel to the first, and filling the space between the two rings with clay. The enclosure is then pumped dry, the ground is excavated, the foundations are laid, and the pier is raised on them to above the outside water level. The cofferdam is then removed.

In such cases it is common practice to sink piles of wood or metal down into the surface on which the foundations will stand (Fig. 89). The stability of a pile does not depend on the resistance of the ground to its point so much as on the friction against its sides. It is well known that though a pile may be driven quite easily provided that the blows follow at short intervals, it becomes immovable if driving cease for a considerable period. This is especially noticeable with piles driven into sand.

Chapter VI.

THE ERECTION OF A TRESTLE BRIDGE.

Raising girders *versus* building out—The Britannia Bridge—The Gôkteik Viaduct, Burma—Transporting the parts from Pennsylvania to Burma—Quick unloading—The beginning of the bridge—Lowering the parts into position—A tall tower—The value of organization.

IN the construction of long trusses of great weight, it is usual, where natural conditions permit, to build stout "falsework" platforms (see Fig. 84) up to the level of the pier heads, and on them assemble the members of the truss. This method is now generally preferred to that of building the truss on the ground and raising it as a whole to its final position. Robert Stephenson was compelled by vexatious conditions laid upon him to resort to the second method for placing the tubular girders of the Britannia Bridge,* and an anxious time of it he had while lifting the gigantic 1,500 ton, 460-foot, tubes from the

* Across the Menai Straits.

surface of the Straits to their lofty seats 230 feet above, using extremely powerful hydraulic jacks for the purpose. The same may be said of Brunel, who raised the 1,200-ton bowstring girders of the Saltash Bridge 100 feet or more on to their piers.

Where it is impossible to erect falsework, trusses are sometimes built out on the cantilever principle, united in mid-air, and then cut into their destined parts over the piers.

For lofty trestle bridges, such as are found in many parts of the United States, the cantilever "traveller" crane is largely employed. Such a crane starts at one end of the bridge, erects a column, lays girders from the abutment to the column, advances on to the girders, erects the next column, lays the next span; and so on till the bridge is completed.

The Pennsylvania Steel Company, of Steelton, Pennsylvania, have been good enough to furnish me with excellent illustrations and a good account of the construction of a steel "trestle,"

THE GÔKTEIK VIADUCT,

in the Shan States, Upper Burma. This viaduct forms part of the railway running from Mandalay to

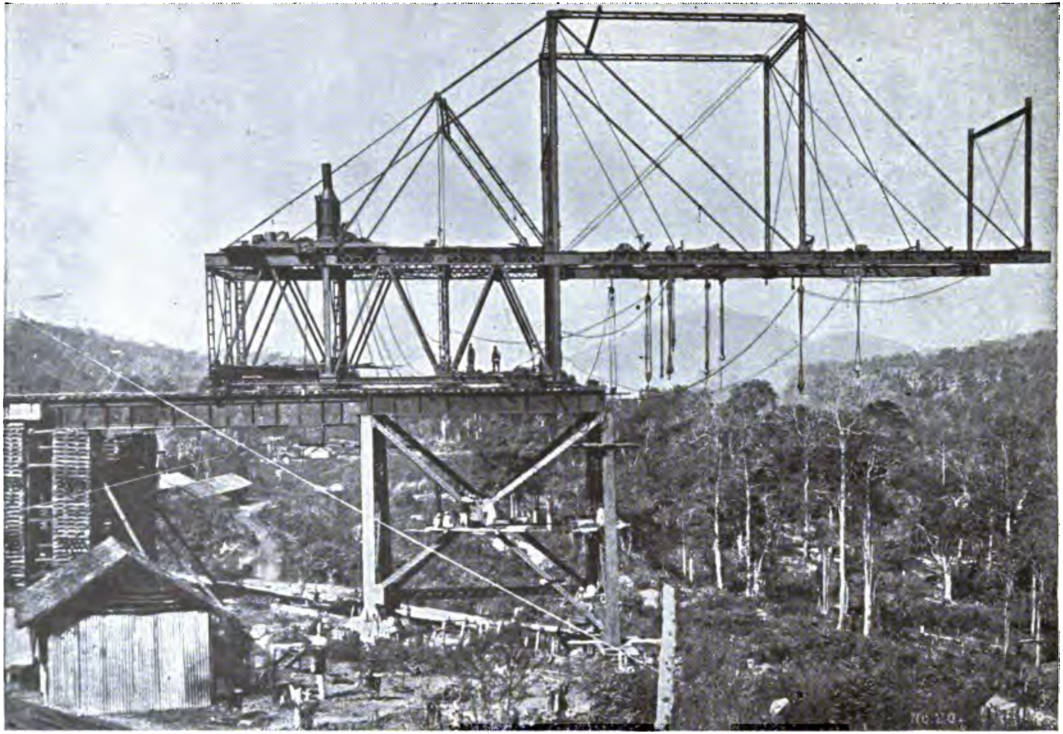


FIG. 90.—The " traveller " for building the Gökteik Viaduct, in course of erection.

Kunlon on the frontier of China. It crosses a deep, wide valley, its trestles being themselves supported by a natural bridge several hundred feet above the stream at the bottom of the gorge. The structure, 2,260 feet long, has seven 60-foot plate-girder spans, and ten 120-foot lattice-girder spans, resting on skeleton towers, the tallest of which is 320 feet high.

All the metal parts were prepared in the United States, drilled for rivets and pins, assembled, disconnected, and shipped to Rangoon, *viâ* the Straits of Gibraltar and the Suez Canal. Thence the Burma Railway took them to the scene of operations 460 miles up country. To use the words of the company's resident engineer, "The storage yard at the bridge head became a scene of mad activity. As the material came in from Mandalay, our big steam derricks whipped it out of the little, metric-gauge freight cars, and swung it over to the smaller derricks for final deposition, and coolies swarmed about with smaller pieces. The work went on with such speed that the engine-drivers and train hands could not shift empties in time to keep clear of the rush. So, when too many of them accumulated, we picked them up with the 15-ton steam derrick, and set them down on the bank, where the drivers of the switching locomotives would

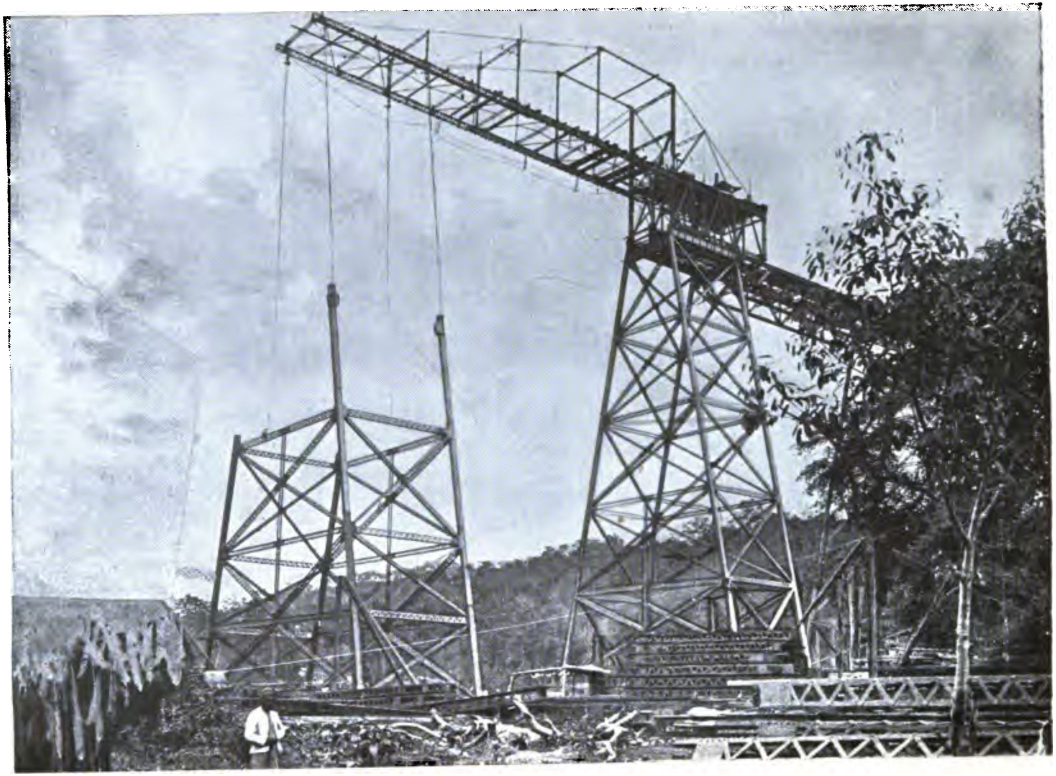


Fig. 91.—Erecting a steel tower, Gökteik Viaduct.

discover them, fifty feet below the level of the track, piled up like empty dry-goods boxes."

The great "traveller" crane was then erected on the railway track at the south end of the bridge. It had a width of 24½ feet, and an "overhang" of 165 feet. The rear end was counter-weighted and could be anchored to the track to prevent any tipping up when the cantilever arm carried heavy loads. Its general appearance and proportions will be gathered from Figs. 90 and 91. Fig. 90 shows it in course of erection, while in Fig. 91 it is seen engaged on the construction of a steel tower.

As soon as it was in working shape, the materials for the first tower were taken to it in due order, lowered, and bolted in position, ready for the riveters, some 350 of whom were employed on the work. These quickly closed the rivets, and then "the big girders for the intervening space between the constructed tower and the abutment on the bank were swung out; the longitudinal stringers and the cross floor beams followed; ties and rails were laid for the trains with material, and tracks were laid on the girders for the traveller to run on. When everything had been completed, tackles were made fast to the traveller, and to the forward end of the girders, lines

were carried to the winding engine, and the big 100-ton machine moved slowly forward to the edge of the newly finished structure. There it was bolted down in readiness for the next tower. To see it move ahead like a colossal drawbridge hundreds of feet in the air until the overhanging beams seemed on the point of toppling the whole mass into the gorge was a sight that the natives could never look on with equanimity."

Fig. 92 includes the highest tower of the viaduct, of nine stories of 35 feet each, braced in all directions. Below the third story from the top, the middle point of the transverse horizontal struts in each tower are supported by an intermediate central column. The central column is double, with six columns, which straddle apart 156½ feet at the ground. The tops of the columns are connected by plate girders, 60 inches deep, to carry the longitudinal girders supporting the track and the ends of the span trusses.

White workmen were employed on the "traveller" and on the topmost points of the rising towers, where the greatest skill and care were needed; some of them nimble sailors who climbed the steelwork like cats and could keep a steady head at any elevation in ticklish places. Nine hours a day the men worked, except when the monsoon raged up the gorge or the sky

emptied itself in a tropical deluge. Pith helmets and thin khaki clothes were the only wear, with the sun blazing down hotly and almost vertically. But Old Sol didn't make much difference. Length after length of the column members were lowered from the traveller, outlined against the hard blue sky overhead, seized by ready hands, pinned into place, connected up with ties, and riveted, while the advance guard were already climbing to receive the materials for the next story. The coolies gaped to see the spidery structure rise at the rate of fifty feet a day.

A tower completed, a truss, which had been riveted by the natives on the end of the bridge, was put on trucks and rolled forward under the traveller, picked up, moved slowly along under the projecting arm, and lowered on to its bearings. In some instances a girder was lowered in two parts which were riveted together in mid-air.

So accurately had all the parts of the structure been made and fitted in Steelton that they went together again with no difficulty. The system of using different colored paints to help distinguish the parts also promoted speed. Every week progress reports were telegraphed to the States, according to an elaborate prearranged code which made it possible to

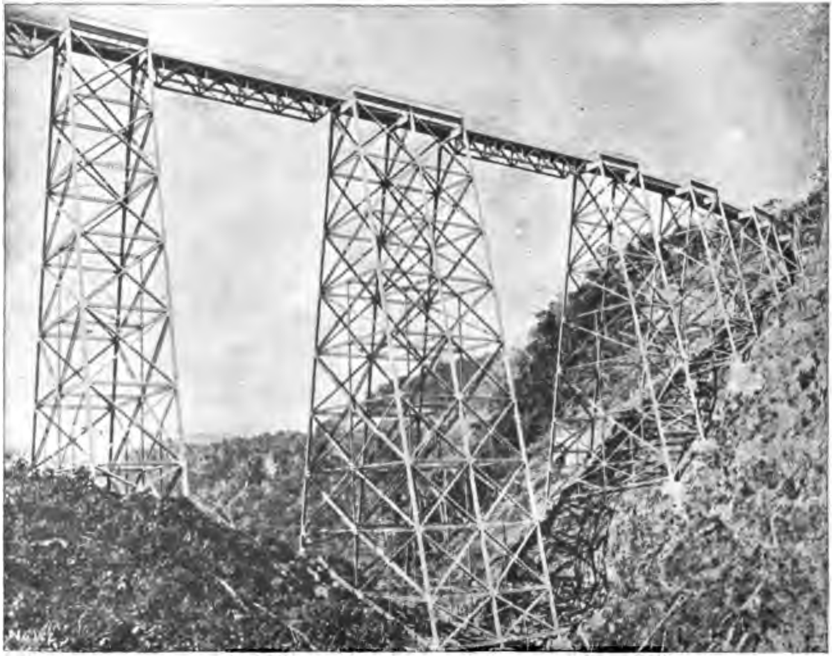


Fig. 92.—The tallest tower of the viaduct: height, 320 feet.

convey a lot of information in a very few words. Within nine months of the erection of the traveller crane the last dab of paint was put on the finished steelwork of the viaduct, and all was ready for laying the tracks. Five thousand tons of metal had been placed; some 200,000 rivets driven.

The rails having been laid, the railway company tested the structure for two months under heavy loads, and expressed their entire satisfaction with the workmanship.

At the time of its completion the Gôkteik Viaduct was the second loftiest trestle bridge in the world, and for combination of height, length, and weight of material, easily first. So far as I am aware it has not yet been surpassed. Whether it has or not, it testifies to the development of the bridge-building art. Two hundred and thirty thousand odd pieces were shipped 10,599 miles in the confidence that they could all be assembled under strange conditions without a hitch; and the faith justified itself. Not a stick of staging had to be raised to help in the placing of the trusses, thanks to that excellent invention, the "traveller," which seems destined to find a wider and wider scope in engineering work.

At present only one pair of rails has been laid over

the viaduct, but there is room for a second when the traffic requires a double track.

The viaduct is straight for 1,638 feet at the centre, and has terminal curves of 800 feet radius, and 341 and 281 feet long respectively.

Chapter VII.

SUSPENSION BRIDGES.

The great suspension bridges over the East River, New York—The Brooklyn Bridge—Its dimensions and carrying capacity—The cables of a suspension bridge—Problems of their formation—Constructing temporary foot-bridges across the river—Spinning the cable wires—How it is done—Clamping and covering the cables—The Manhattan Suspension Bridge: 23,000 miles of wire —Facts and figures.

A SINGLE square mile of the earth's surface includes the three greatest suspension bridges in existence—the Brooklyn, the Manhattan, and the Williamsburgh, all of which span the East River, and form three of the great arteries of traffic between New York and Brooklyn. To be quite correct, the Manhattan Bridge is at present only in course of construction, but its towers are up, and ere long its great cables and stiffening girder will dominate the shipping on the river, and we may therefore look forward a little and include it among present bridges.

The Brooklyn Bridge has been described so often

that it will suffice to glance at the following facts and figures relating to it. It was begun in 1870, and opened for traffic in 1883. Its masonry towers rise 272 feet above, and reach 78 feet below, high water—350 feet in all from rock to summit. Between them they consumed 85,000 cubic yards of masonry; and the two massive anchorages required as much again. The main span is one of 1,595½ feet, and the two shore spans, from towers to anchorages, are 930 feet long each. Add the approaches, and you get the total length of a mile and a furlong.

The cables, four in number, each contain 5,296 steel wires reaching from anchorage to anchorage, a distance of 3,572 feet. This gives a total of 14,000 miles of wire. Each cable has a diameter of 15¾ inches, and a breaking strain of about 12,000 tons.

The roadway, 85 feet wide, is divided into two carriage tracks, two street railway tracks, and one footway. The rise of the stiffening girder towards the centre of the span increases the headway between river and bridge from 119 feet at the towers to 135 feet in mid channel.

Vast as are the proportions of the Brooklyn Bridge, those of the Williamsburgh surpass them. This wonderful structure has a total length of a mile and 1,920

feet, including a main span of 1,600 feet and two shore spans of 600 feet. The four cables are each 19 inches in diameter and built up of thirty-seven strands, each strand containing 208 wires, each 3,020 feet long. Figure this out and you get 19,000 miles of wire; which, it may interest you to know, weighs 5,000 tons. The wire used, by-the-bye, has a diameter of $\frac{3}{16}$ of an inch.

Turning for a moment to the towers—steel in this case—we learn that they rise 335 feet above high water. The masonry anchorages to take the pull of the cables are of the most massive description, 150 feet long, 150 feet broad, and 100 feet in height above the ground. As for the stiffening girder, it is composed of two parallel lattice-work trusses, 67 feet apart and 40 feet deep—too deep for beauty, but necessarily so to stand without perceptible distortion the huge moving load to which it is subjected. The floor of the girder is extended 20 feet on each side outside the trusses. It gives accommodation for four street railway tracks, two elevated tracks, two eighteen foot roadways for vehicles, two passenger footpaths, and two cycle paths, so the bridge may therefore be considered more roomy than any street in New York.

Let us take the foundations of the towers, and the

FIG. 93.—View of footbridge used for making the cables of the Williamsburgh Bridge.

towers themselves, and the anchorages for granted as built, since they afford no very striking features, apart from their huge dimensions, to delay us, and pass on to the consideration of the mighty cables which are the most interesting parts of a wire suspension bridge.

The wires in such cables are not twisted like those of a rope, because twisting, though it serves to keep wires together, subjects them to different degrees of strain. It is of the utmost importance that every wire in a suspension bridge cable should bear no more or no less than its fair share of the weight. This condition is fulfilled by forming the cables of parallel wires bound, not twisted, together.

Now, what was the task confronting the constructors of the Williamsburgh cables? First, to calculate the exact weight which the cables would have to support, the extent of their dip in the centre of the main span, their exact shape and position when finished; the tension on the cable due to its own weight. These calculations must include due allowances for variations in temperature. Second, to make preparations for spinning 19,000 miles of wire across a busy waterway. Third, to form the cables and protect them from the weather.

In the anchorage at each end were embedded huge plates, and attached to these plates were large numbers of anchor chains made up of series of eye-bars*—four chains to every three strands in every cable. On the top of each tower rested four massive saddles of cast steel to carry the cables, mounted on rollers so that they might move a few feet in the direction of the axis of the cables, and ease the strain caused by variations of temperature and load on the bridge. Every wire would start from one anchor chain, rise to the top of the nearer tower, cross the river in a vertical curve, exactly regulated, to the further tower, and descend to its anchor chain on the other bank of the river.

The mere placing of the saddles preparatory to spinning the wires required much calculation, as the attachment of the stiffening girder to the cables would draw the cables down in the central span, and cause the saddles to move on the towers. Any mistake could not be remedied when the cables were once in position.

The saddles having been set, preparations were

* An eye-bar is a long, flat bar of steel with expanded ends pierced by holes for the pins which connect the bars. The side plates of the links of a bicycle chain are eye-bars of very small dimensions, and the rivets represent the pins. (See Fig. 94.)

made for slinging a temporary light suspension bridge from anchorage to anchorage to afford the workmen easy access at all points to the cables during construction. The bridge had four footwalks—one for each cable—3 feet below the imaginary line of the

FIG. 94.—Transferring a wire from the travelling sheave to its "shoe."

cables during spinning. In the main span there was a lower deck of four footways similarly spaced from the line that the cables would take when the strands had all been formed and placed in their final positions on the saddles.

MAKING THE FOOTBRIDGE.

The footbridge was supported by sixteen wire cables, 2¼ inches in diameter, in four groups of three ropes each, and a single rope over each group. This is how a cable was slung. A tug took it, wound on a reel, to the foot of the New York tower, where it was transferred to a lighter carrying a hoisting engine. A rope was passed from the lighter over a pulley on the tower and down again to the deck, and attached to the cable, 60 feet from one end. The loose end was lifted to the top of the tower, drawn by another engine back to the anchorage, and made fast. The floater then crossed to the other tower, paying out the cable, which sank to the bottom of the river. The 400 feet remaining on the reel were now unwound and laid on the deck, and the end sent up the tower. On the Brooklyn shore stood a very powerful hoisting engine, which was connected up with the cable. All being in readiness for the final pull, patrol boats stopped the traffic in both directions, and as soon as the stream was clear the hoisting engine started work. Slowly rose the cable, until its centre swung 150 feet above the water, but it could not be made fast until adjusted to the exact deflection required as

ascertained by means of levels and transit instruments. So in turn all sixteen cables were treated; and over them were laid planks to form continuous footways, connected at short intervals by bridges. This part of the work was greatly facilitated by four traveller cranes, starting from the towers and working down towards the centre of the main span and to the anchorages. A general view of the bridge is given in Fig. 93.

SPINNING THE WIRE.

The next piece of business was to install machinery to carry the main cable wires across the river. This consisted chiefly of two endless travelling ropes, ¾ inch in diameter, supported at intervals on pulleys attached to the footbridge, and driven by steam-engines with appropriate gearing stationed at the New York end. The ropes ran from anchorage to anchorage just above the line of the cables. It should be explained that the one rope crossed the bridge over the first cable and returned over the second, while the other served the third and fourth cables in like manner. An elaborate installation of electric bells and telephones was a necessary adjunct of the ropes.

The method of cable-forming used on the Williams-

burgh Bridge is that invented in 1844 by Mr. John A. Roebling, and employed by him and his successors on the Niagara, Cincinnati and Covington, and Brooklyn bridges. It may be added that the John A. Roebling's Sons Company was responsible for the cables now under consideration.

What the method is may be understood easily with the help of Fig. 95. The thick dotted line represents one endless rope, carrying two sheaves, X and Y, sus-

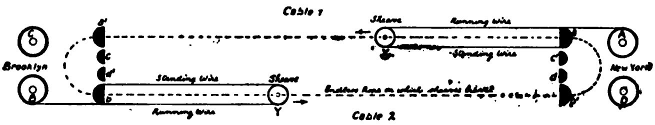


FIG. 95.—Diagram to explain the "spinning-in-the-air" method used to form suspension-bridge cables.

pended from it by "goosenecks"—iron bars curved to clear the supporting pulleys without hindrance.

The sheaves are so spaced on the rope that when the one is at the Brooklyn anchorage the other is at the New York anchorage.

At each anchorage are two large reels of $\frac{3}{16}$-inch wire, A, D, B, C. The solid black semicircles, *a, b, c, d, a,[1] b,[1] c,[1] d,[1]* indicate the "shoes" round which the wires of four strands—two for cable 1, two for cable 2—will be wound. These shoes are attached to

anchor chains, but not in their final positions, as adjustment will be required after the strands are complete.

We will suppose that the workmen are about to commence stringing wires round a and a^1, and b and b^1. Those on the New York side unwind an end of wire from reel A, attach it to shoe a, and pass a loop of it round sheave X. Simultaneously the Brooklyn party has attached the end of the wire at reel B to shoe b and formed a loop round sheave Y. The signal is given and the rope begins to move, gradually extending the loop on each sheave, and unwinding the reels. The side of a loop which is attached to the shoe is called the "standing wire," and the reel side the "running wire," which travels twice as fast as the sheave.

On completing the journey, the loop on sheave X is transferred to shoe a^1 at the Brooklyn anchorage, and the loop on sheave Y to shoe b^1 at the New York anchorage. Fig. 94 shows a sheave arriving and a workman attaching a tackle to the wire preparatory to its removal from the sheave.

On the return journey the sheave X carries a loop from reel C, its end fixed to shoe c; and sheave Y a loop from reel D, its end fixed to shoe d. Be it under-

stood that the direction of the rope's travel is *reversed* between every two journeys, sheave X plying back and forth over cable 1, and sheave Y over cable 2.

When the sheaves reach their original starting-point the new loops are transferred to shoes c^1 and d^1 respectively, and eight wires have been slung, and two strands begun in each of the cables. On alternate journeys sheave X draws out loops from reels A and C, and sheave Y draws out loops from reels B and D. During the construction of the Brooklyn Bridge cables only one reel was used for each cable, and the sheaves had to return empty one way. The stringing of those cables occupied twenty-one months; but the adoption of the double-ended method described above—and greater experience—reduced the period to seven months for the Williamsburgh Bridge. The maximum weight of wire slung in one day was 19½ tons for the Brooklyn Bridge, and 75 tons for the Williamsburgh.

Such, in brief, is the system of "spinning in the air" invented by Mr. J. A. Roebling.

Before the spinning could be actually commenced it was necessary to hang *guide wires,* of the same size and quality as those in the cables, two for each cable —since, as we have seen, *two* strands were formed by

each sheave. To make things quite clear to the reader, it should be explained that the wires passing round shoes *a* and a^1 form one strand, those passing round shoes *b* and b^1 a second strand, for cable 1; while shoes $c\ c^1$, $d\ d^1$, hold two strands for cable 2.

FIG. 96.—A view of the strands of a cable.

The guide wires were strung from anchorage to anchorage, and marked at points on the saddle. The length of wire between the saddles was the same for all strands, but that of the parts between saddles and anchorages varied, owing to the shoes being at different distances from the anchor plates. These variations were carefully allowed for.

The guide wires were transferred from the saddles to stationary sheaves at the side of the saddles in which the strands were formed. Up came the sheave carrying the first loop of a strand from the anchorage. When it reached the nearer tower, the standing wire of the loop was adjusted to hang parallel to the guide wire, and bound to it with twine at points 50 feet apart, and the running wire laid in pulleys on which it moved without friction. The adjustment completed, the men on the tower clamped the standing wire. The main span was similarly adjusted from the further tower and clamped, and the second land span from the other anchorage. The running wire was next adjusted in the reverse order, and the two first wires of the strand had been well and truly laid. This operation having been repeated four times, the guide wire was removed from the saddle sheaves and laid aside until the commencement of the next strand.

When the travelling sheave had made 104 journeys the wire of the strand was disconnected from the reel feeding it, and the ends joined up. Now followed the operation of slacking off the strand at the anchorages till the shoes came into place between their eye-bars on the anchor-chain, and could be finally pinned, and of lowering the strand from the saddle sheaves into its

final position on the saddle itself. These operations were accomplished by means of powerful screw apparatus.

Thirty-seven strands, arranged in a hexagonally shaped group, formed the cable, which had to be squeezed and bound with twelve turns of wire every

FIG. 97.—Adjusting clamps to bind cable strands together.

4 feet, and with large saddles for the suspenders of the stiffening truss. For the squeezing were used powerful steel bands tightened up by bolts and nuts. In Fig. 97 are seen some men at work with the squeezers. When the cable wires had been beaten with wooden mallets and constricted to the smallest possible

diameter, the wire "serving" was applied close to the bands, and the latter were removed.

To make all snug against the weather, the cables received a wrapping of waterproof material and an outside covering of sheets of thin steel.

It is interesting to note that, though the work of cable stringing was necessarily of a very dangerous character, only one man lost his life—by falling from the footbridge into the river far below.

THE MANHATTAN BRIDGE.

Between the Williamsburgh and Brooklyn bridges the engineers are busy on the great Manhattan Bridge, which, though of less span than either of its neighbors, excels them both in its weight-bearing capacity.

The original plans for this bridge specified eye-bar chains* to carry the stiffening girder, but it was finally decided to employ cables of unprecedented size. At the risk of wearying the reader I shall state that each of the cables contains 9,472 wires, and has a diameter of 21¼ inches. The total length of wire consumed will be 23,000 miles—almost sufficient to girdle the earth at the equator. As the wire used can withstand a pull of about 2¾ tons, each cable

* Eye-bar chains were adopted for the Tower Bridge, London.

FIG. 97a.—A tower of the Manhattan Suspension Bridge. Each of the four legs measures 5 feet by 32 feet at the base, and rises 322 feet above the water.

(*Photo, " The Scientific American."*)

would be able to suspend a couple of ironclads weighing 12,000 tons each. The cables will be required, however, to endure the strain of but one-third of their breaking strain in the task of supporting a stiffening truss to carry eight railway tracks, two footpaths, and a roadway for vehicles.

The total weight of the steel used in the bridge will exceed 40,000 tons, of which 13,000 tons will be absorbed by the great towers, whose tops are 332½ feet above high-water level, and whose bases rest on great masses of masonry reaching down to the rock 92 feet below high-water level. The total height of tower and foundation is therefore 424½ feet—approximately the same height as that of the Forth Bridge towers and piers. Each of the anchorages measures 237 feet from north to south, and 182 feet from east to west, and rises 135 feet above ground. The weight of each, 233,000 tons, will easily resist the tremendous pull of the cables.

One feature of the Manhattan Bridge that will distinguish it from its rivals is that the cables will not rest on movable saddles, but be permanently attached to the towers, which will bend slightly under variations of load. Another novelty is the employment of nickel steel for the top and bottom chords of

the four trusses of the stiffening girder, to save weight by its extra strength, as compared with ordinary steel.

NOTE.—The photographic views illustrating this chapter were kindly supplied by Messrs. John A. Roebling and Sons, New York.

Chapter VIII.

CANTILEVER BRIDGES: THE FORTH BRIDGE.

A glimpse of the Forth Bridge—The cantilevers—The towers—Skewbacks—Balancing the arms—Facts and figures—Preparations for erection—Making the tube plates—Riveting—The rising platforms—Adjusting the columns—The top chords—Building the cantilever arms—Ticklish work—The suspended girders—Joining up—A delicate operation—An exciting incident.

THE principles of the cantilever bridge have been explained on a previous page. It is now time to turn to an example or two of cantilever construction. There rises at once before the mind the huge Forth Bridge, which for years past has been the greatest of all cantilever structures, and will in some respects continue to be so even when the Blackwell's Island Bridge and the ill-fated Quebec Bridge are completed. Many accounts have been written of the building of the Forth Bridge, yet an apology is hardly needed for introducing the story of a great engineering triumph—the story of seven years of ceaseless and successful work, consummated on March 8, 1890, when, to the

music of a gale raging through the criss-cross of steelwork, the (then) Prince of Wales declared the bridge open to traffic.

Fig. 98 will help you to gain an idea of what the Forth Bridge looks like as seen from the flank. Let us imagine ourselves passengers on a boat passing up the Firth of Forth. For miles the great outlines of the bridge dominate the landscape. As we approach, the estuary contracts to a width of about a mile and a quarter, between North Queensferry and South Queensferry; and soon we are almost under the bridge, and obliged to bend well back so that the eye may travel up to the top of the structure.

Our guide takes up his tale. "Ladies and gentlemen, it will interest you to learn that the railroad track is 150 feet above high water. You observe that there

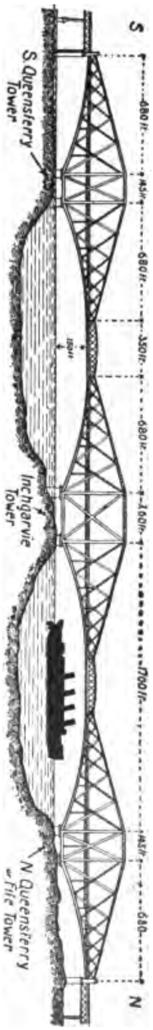


Fig. 98.—Diagram of Forth Bridge, showing principal dimensions. Under the north span is a vessel of the relative size of the *Mauretania*.

are six cantilever arms. Well, each of these is 680 feet long, and the two suspended girders carried by four of them are 350 feet long; so that each of the two main spans, reckoned from tower to tower, is one of 1,710 feet—the greatest of all bridge spans. The towers? Yes! they are 342 feet from pier to summit, each consisting of four great tubes, 12 feet in diameter, built of plates riveted together. As you see, they are braced by other great diagonal tubes and by lattice girders, and though the columns appeared parallel as we approached, now that we are under the bridge you notice that they incline towards each other over the track. To be exact, the columns of each pair are 120 feet apart at the bottom and only 33 feet apart at the top.

"The cantilever arms have straight upper chords of lattice form and tubular lower chords. The last are built up of tubes which have a diameter of 12 feet at the bottom and gradually taper away towards their outward extremities. The upper and lower chords on each side are connected by six tubular struts and as many lattice ties, forming six bays, as the engineer terms them. Please notice that all 'members' — the engineer again — that have to withstand compression are tubular in this bridge,

and those which are in tension are lattice-work girders.

"Now consider the piers for a moment. They are twelve in number, distributed in three groups of four among the towers. Tops, 19 feet above high water, and 45 feet in diameter. Best granite work on concrete below-water foundations. To the upper surface of each a great bedplate is bolted down—weighs 44 tons; 5 inches thick. Another bedplate is attached to the bottom of the skewback of the column which it supports. The upper bedplate rests on the lower bedplate, and three out of the four upper plates for each tower are able to move a little over the under ones, to allow for expansion and contraction and varying wind pressure. 'Skewbacks?' They are the great junctions at the bottom of the columns, where five tubular and five lattice members meet. Very complicated bits of work, eh! I warrant Sir Benjamin Baker and his friends had to think about them a lot.

"Are the end cantilevers out of balance? No; because the ends of the arms which rest on the masonry of the approach viaducts are loaded with dead weight equal to half that of the suspended girders carried by their fellow arms. Some one asked

why the middle tower is so much longer than the others. You see, neither of its arms is supported, so it has to be made extra long to prevent any tendency to tip up if two trains happen to meet at the end of an arm. It is 260 feet long, as compared with the 143 feet of the others. By-the-bye, wasn't it a lucky thing that the Inchgarvie rock happened to be in the middle of the channel? It saved the engineers a lot of trouble.

"More facts and figures? Well, the bridge, including its approaches, has a total length of 8,295 feet 9½ inches. The superstructure contains 50,958 tons of steel, and required 6,500,000 rivets to fasten it together. It's very strong, is the Forth Bridge. Sir Benjamin Baker told an audience that a battleship could be hung on the end of each cantilever arm without causing the ties at the tops of the towers to part. It may interest you, in conclusion, to be told that there are 145 acres of surface to be painted every three years."

Now let us throw ourselves back in imagination and watch

THE BUILDING OF THE FORTH BRIDGE.

The south shore of the firth has been terraced to accommodate shops and yards and a small town of houses for workmen. Special railways have been laid;

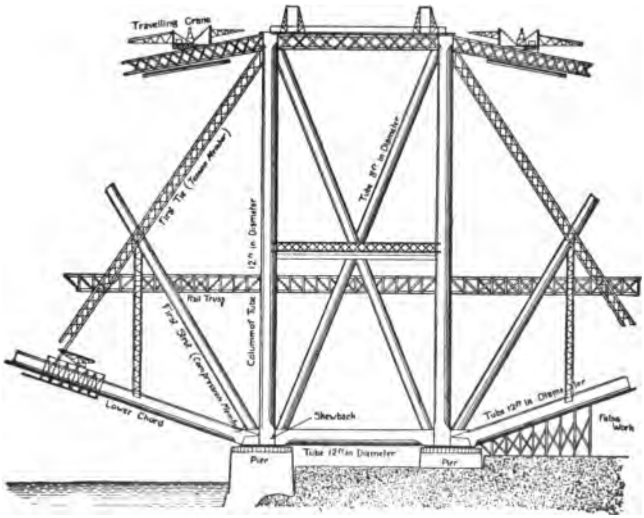


Fig. 99.—Diagram to show how the cantilever arms of the Forth Bridge were built out.

telephones and telegraphs installed; a water supply provided. Engineers have established the exact positions of the main circular piers by trigonomet-rical calculations, and checked them with long wires

of a carefully measured length. The two north Fife tower piers have been built on the water-free rock, their southern fellows inside cofferdams. The Inchgarvie north piers also rise inside circular steel casings shaped to fit the rock below, and the two south Inchgarvie and all four South Queensferry piers have been built with the aid of pneumatic caissons after the manner described in a previous chapter.

On shore men are busy preparing the great tubes of the bridge. The plates for these are shaped to the correct curve in rolling-mills, trued up in a hydraulic press, and passed through a great machine which drills rivet holes in them. As fast as they are prepared they are marked and transported to the piers, where platforms and winding tackle are in readiness for the commencement of the superstructure.

The skewbacks are already in place, and joined to one another by horizontal tubes and girders spanning the gaps between the piers. Upwards in many directions they send out the stumps of great members which will presently extend hundreds of feet into the air.

Steam-derrick cranes lift plate after plate of the columns and hold them in place for the riveters. These plates prove on close inspection to be half an

inch thick. Every one is 16 feet long and 3 feet 9 inches wide. Ten of them—five inside, five outside—riveted together by their longer sides form a length of tubing. The vertical joints are strengthened by girders of T section, the head riveted in with the joints, and every 8 feet is placed an internal circular diaphragm slotted at the circumference so as to pass the girders and reach the shell. These share with heavy plate girders, more widely spaced, the task of preserving the true circular form of the tubes.

Allowing the hour hand of our mind-clock to reel off the weeks as if they were minutes, we see the columns rise to a height of 50 feet above the piers. The cranes cannot lift the plates any higher; so a second staging is constructed 38 feet above the first, and on this are built two pairs of great iron girders, each longer than the tower, running north and south in the line of the bridge and close to the columns. Let us call them the A girders. These rest on two cross girders, B, pointing east and west, their ends projecting through the columns, and below these are two beams, C, bearing on the columns. Hydraulic rams, resting on C, support B, which in turn support A, on which are constructed platforms for cranes and workmen. Thus there are two platforms of about 25 feet

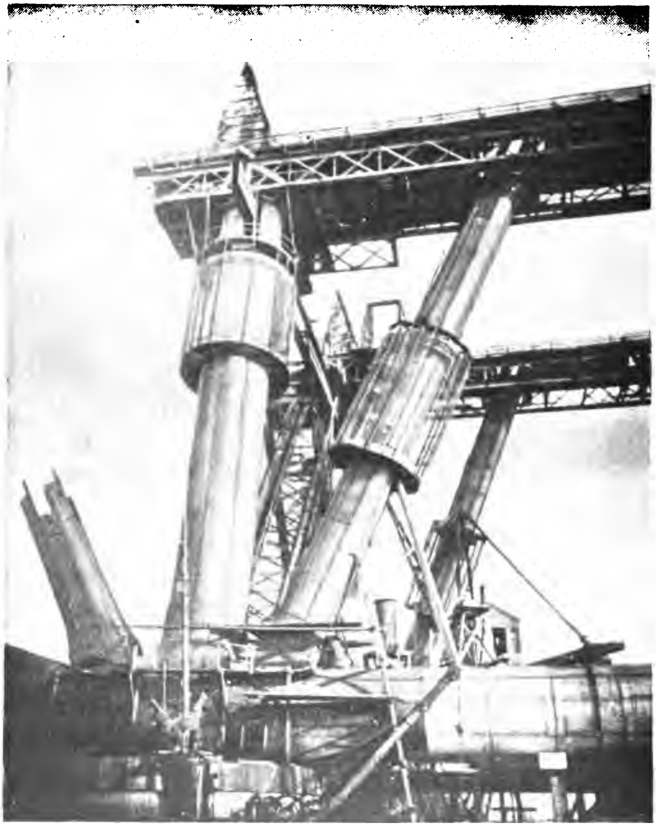


FIG. 100.—The Fife Tower, Forth Bridge. Observe the rising platforms—supported by cross girders projecting through the columns—and the riveting cages below.

(*Photo by the late Sir Benjamin Baker.*)

wide and 200 feet long (350 feet long in the case of Inchgarvie) completely embracing and projecting some

distance beyond the vertical columns. As the towers rise they will approach one another.

Encircling the columns below the platforms are riveting cages, and inside the columns are corresponding cages, so that the riveting gangs may be drawn up after the platforms when the latter are raised.

The hydraulic rams have a stroke of one foot. Everything being ready, those under one of the B girders are set to work. The girder rises a foot and is secured. The water is released from the ram, and the ram's support raised a foot. Then the other B girder is treated in the same way; and so on alternately till the platforms have risen 16 feet, the full height of a plate.

Another course of plates is then built on with the help of the cranes, and meanwhile the men in the cages below add the plates omitted on the line of the B girders and complete the riveting.

At intervals it is necessary to adjust the columns to the exact inward inclination required, forcing them apart with struts and rams till the line is correct. Simultaneously with the columns the main diagonal struts have progressed, and the diagonal cross ties under the railway track which will be. At the point where the struts cross one another some very intricate

work is done, consuming many tons of steel. Horizontal bracing is built in between the columns on one side of the central line and those on the other. Half-height has been reached. A large platform can now be built on which to store materials for the upper half of the tower. The riveters do not stop. Inside and outside the columns they work their hardest, squad vieing with squad. Every hour each machine closes its 80 to 90 rivets.

At last the platforms reach their final position, and preparations are made for building the horizontal top ties for the columns. These are large lattice girders. The workmen first rivet up the bottom chords, then attach the lattice webs and add the top chords. As soon as the ties are self-supporting they are lifted from the platform on to the columns and made fast.

The summit junctions next receive attention. Since they are almost as complex as the skewbacks, the assembling of all their members is not an easy matter, and to shelter the workmen engaged quite large three-story houses are erected 360 feet above the water.

After the completion of the top work the travelling platforms are dismantled and transferred to the very summit of the towers.

THE BUILDING OF THE CANTILEVERS.

The work that follows is full of anxiety for the engineers, for it will put a much greater strain on the steelwork than heretofore. Refer to Fig. 99. This shows us two great travelling cranes, each weighing with its platform and gear some 64 tons, advancing into space along the top members of the cantilever arms, building them out as they move. The stress on these members—as yet entirely unsupported either vertically or laterally—means risk of disaster should a heavy gale blow up. From below rise the first compression struts and the lower chords—these also unsupported—and the railway truss projects its ends far beyond the columns. Downwards the first ties are approaching the lower chords, to which they have already been connected by permanent vertical supports.

At length the strut tops reach the upper chords; but before a junction is made the engineers check positions with their theodolites and, where necessary, raise the chords. Then the riveters become busy, and soon the first bay of the cantilever is secure, and the cranes may pursue their aërial journey.

For each bay the same progress is repeated, the big cranes aloft feeding the workmen on the upper booms and the struts and ties in course of formation, while along the bottom chords advance riveting cages and cranes attached thereto. The amount of work proceeding on the two cantilever arms is kept even, so

FIG. 101.—General view of the partly-built cantilevers.

that there may be no unnecessary strain on the columns. Each bay is shallower and narrower and lighter than its predecessor, and is erected more quickly. At the end of the sixth bay the arm is closed by a hollow box—4½ feet deep, 3 feet wide, and 40 feet high—open on the side facing the central girder.

THE SUSPENDED GIRDERS.

So lengthy a structure as the Forth Bridge must necessarily shrink or expand longitudinally to a marked degree as the heat of the atmosphere falls or rises.

Due allowance for such changes is made at the points where the end cantilevers rest on the viaducts and at the points of junction between the Inchgarvie cantilevers and the two suspended girders. These last are also able to move slightly in a circular direction at both ends.

The suspended girders were built out from both ends and connected at the middle, and the ends then released. The weight of the girder rests on its top chords, which, during erection, were attached to the upper chords of the cantilevers by short tie plates. Between the bottom girder chords and the bottom of the cantilever end big wedges were driven in, so as to give the half girder a slightly upward inclination. This was needed in order to counteract the bending which took place as the halves were built out, and to bring the parts of the bottom chords into line.

The travelling cranes already referred to were employed for the suspended girders, moving along

the top chords and hoisting up material from barges in the river. Eventually these cranes, which had started from the summits of the towers, met in pairs at the centre of the girders, and their work was done.

Now came the delicate and difficult work of joining up the girder halves. As the work had to be supported by the temporary end ties until the junction had been made, it was necessary to effect the join in a temperature which would give the parts of the girders the exact length required. First the bottom chords were completed, the free ends being drawn together by hydraulic power and heat, and riveted to cover plates. There remained V-shaped gaps in the upper chords and webs, 10 inches across at the top and tapering downwards. Plates to fill these gaps exactly were made and attached to other plates which would be riveted to the upper chords. These plates and the upper chords were drilled ready for their rivets.

The engineers had now to wait for the time when the temperature should fall to a certain point and widen the gap till the wedge plates could be inserted and fixed. Meanwhile furnaces were arranged round the tie plates to make them red hot when the moment for action should arrive, and ease their tension while their rivets were removed.

At last the gap opened sufficiently. The wedge-pieces were inserted and the steel wedges between the cantilevers and the bottom of the girder drawn out, so as to bring all the weight of the girder on to the top chord and throw it into a state of compression. Men drove the rivets home, while others kindled the furnaces, and separated the ties, and at last the girder rode free, resting on its ends.

At the closing of the northern girder a rather startling incident occurred. After the wedge-pieces had been inserted, and the workmen were cutting the ties, a sudden rise or fall of temperature took place, and the remaining bolts in the ties were shorn through and parted with a noise "like a shot from a 38-ton gun," as a witness describes it.* The whole bridge shook from end to end, and some people feared that there had been disaster. As a matter of fact, nature had merely completed the work in a somewhat dramatic manner.

The laying of the track calls for no special notice, though the bridge was to be the servant of the locomotive. We may be sure, however, that it seemed a very easy and safe business after the many difficulties

* Mr. W. Westhofen in "The Forth Bridge," to which fine account I am much indebted.

and hazards of the work that had preceded it. Of dangers there had indeed been plenty, and some dozens of men lost their lives during the seven years; but the greatest bridge of its kind in the world, reared without setting a single stick into the river bed to support it, will for many years to come be their splendid memorial.

Chapter IX.

THE BLACKWELL'S ISLAND BRIDGE.

The bridge—Its main features—Gigantic pins—How they put the bridge together—Huge stone supports—The island span—False-work—Twin travelling cranes—Making the arms—The capacity of the bridge—A huge arch bridge—Julius Cæsar.

THREE miles north of the Williamsburgh Bridge there rises in the centre of the East River channel a long, narrow rock known as Blackwell's Island. This rock has served the same purpose as Inchgarvie, in the Firth of Forth, for the engineers have utilized it to help support a huge cantilever bridge, which in a few years will unite Sixtieth Street, Borough of Manhattan, with Ravenswood, Borough of Queens, on Long Island.

In length and weight it rivals, in carrying capacity it surpasses, the Forth Bridge itself. The trusses are the heaviest ever built. Fig. 102 shows this great structure in outline. It has six points of support—two terminal anchorages, and four piers—built on the

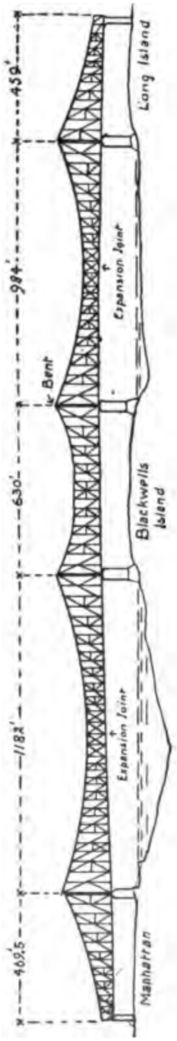


FIG. 102.—Blackwell's Island cantilever bridge.

firm rock through which the river has eaten out a channel. On the east and west edges of the island rise two of the piers, and the other two stand in line on the banks of the river. These piers support four cantilevers, which form two main river spans of 1,182 and 984 feet respectively, an island span of 620 feet, and two shorter shore spans of 469½ and 459 feet, making a total length for the bridge proper of 3,724½ feet.

FEATURES OF THE BRIDGE.

This bridge differs from the Forth Bridge in that—(1) The members are pinned together at points of intersection, not riveted. (2) It includes no suspended girders. In fact, the bridge is practically one continuous girder, with expansion joints at the centre of the river spans. (3) The truss members of the superstructure

were not built up bit by bit near the site, but put together by the manufacturers, the Pennsylvania Steel Co., and forwarded entire on cars or groups of cars, and pinned as the erection proceeded.

A very pretty bit of pinning it has been, too. The things to be connected, great bars and girders, some weighing 120 tons each; the pins, cylinders of steel, some 16 inches in diameter and 10 feet long; the thimble, a 5-ton battering ram. And this pinning had to be done partly at a height of 300 feet above a deep, swift current, navigated by steamers, barges, ferries, and sailing ships, with the bitter winter winds raging furiously.

The tension members of the bridge, the top chords and ties, are eye-bars arranged in groups, so that upwards of twenty eyes would be threaded on one pin. You might think that for things so huge a close fit in the eyes and pins would not be necessary, yet the greatest allowance is $\frac{1}{50}$ of an inch. Much nickel steel was used in both bars and pins.

HOW THEY PUT THE BRIDGE TOGETHER.

The building of the piers was straightforward work, as rock lies close to the surface of the ground. For the piers great quantities of granite were shipped from

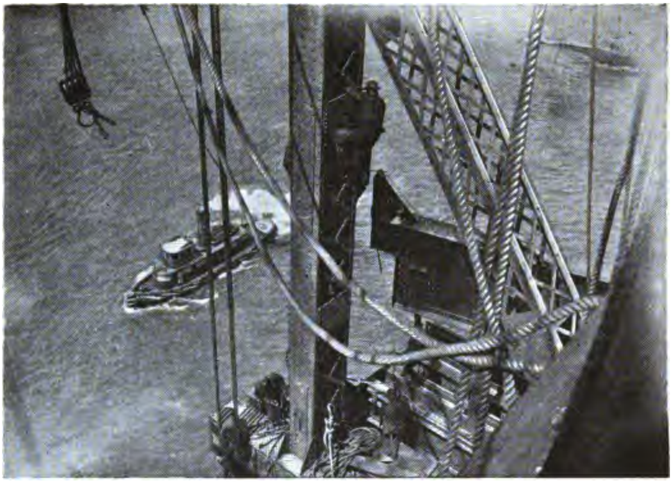


Fig. 103.—Blackwell's Island Bridge. Erecting the cantilevers.
(*Photo, "Scientific American."*)

Fig. 104.—Assembling eye-bars.
(*Photo, "Scientific American."*)

Maine quarries, and dumped in specially built yards fitted with all kinds of ingenious machinery for shaping and handling the blocks. On the top of each pier are two huge stones to support the legs of the central "bents," or legs of the cantilever. These stones measure 21½ by 21½ feet, and are enormously heavy, but they were raised 125 feet into position, set, and planed by special pneumatic machines till there were no variations greater than the thickness of a sheet of paper, and no hollows could be detected by the levelling rod. Then on them were laid massive pedestals, weighing 130 tons or so each, as footings for the bents.

The island span (Fig. 105) was erected first to balance the nearer arms of the two river spans. In order to support the span during construction the engineers built an elaborate steel "falsework" up to the level of the pedestals, and on it assembled the lower boom and a railway for two great travelling cranes, which hauled up and placed the members for the bottom half of the truss, including the two decks which will carry the traffic of the bridge.

The travellers worked from the ends of the span to the centre, closing their paths behind them, and were dismantled when their task was finished.

FIG. 105.—The island span, showing falsework. Observe the two great "travellers."
(Photo, The Pennsylvania Steel Co.)

FIG. 106.—Building out the arms from the island piers. The travellers have passed through the towers.
(Photo, The Pennsylvania Steel Co.)

Two **Z**-shaped travellers, weighing 550 tons each, and having an overhang of 63 feet, were now erected on the *upper* deck at the centre of the span. These had a sufficient height to dominate the truss at all points except near the bents. Moving away from one another they completed the truss, and passed through the bents, the cross bracings of which had been temporarily cut to give them passage. Then the jibs on their summits finished off the bents. During the process of pinning to the truss the bents were pulled inwards by extremely powerful hydraulic rams. December 4, 1906, saw the last pin of the central span driven into place.

This done, the two travellers resumed their journey, moving outwards over the river, one towards Long Island, the other towards Manhattan (Fig. 106). As the river arms grew, the weight of the island span was counterbalanced, and it became possible to remove the falsework, starting from the piers, and use it to support the two shore arms. These were pieced together in much the same manner as the island span, and from them grew out the two remaining arms of the main river spans, which in due course gripped hands with the island cantilevers.

The completed bridge will have a width of 88 feet.

Fig. 107.—Showing Queens anchorage and cantilever arms.
(Photo, The Pennsylvania Steel Co.)

Fig. 108.—Lower floor of island span and cantilever arms.
(Photo, The Pennsylvania Steel Co.)

On the lower deck, between the main trusses, 60 feet apart, there will be a central roadway 36 feet across, flanked at either side by a trolley track. Outside the trusses, supported on brackets, two more trolley tracks are provided for; while on the upper deck we shall see four between-truss tracks, and two outside-truss footwalks, so that, as far as traffic capacity is concerned, the bridge may be reckoned a street 150 or more feet wide. When this steel-borne avenue is opened to the public the bridges lower down the river will not be quite so hard worked, as the districts near the ends of the bridge will draw off some of the population from further south. Already there are schemes afloat for adding yet more bridges to the growing total, as New Yorkers are still unsatisfied. When the Brooklyn Bridge was the only alternative to the ferries the competition for seats in the cars that cross it was terrific at certain times of the day. The rising generation of citizens may congratulate themselves that they have a larger choice. What will become of the ferry boats? They will have to move off to other districts, where there is still room for them to be useful.

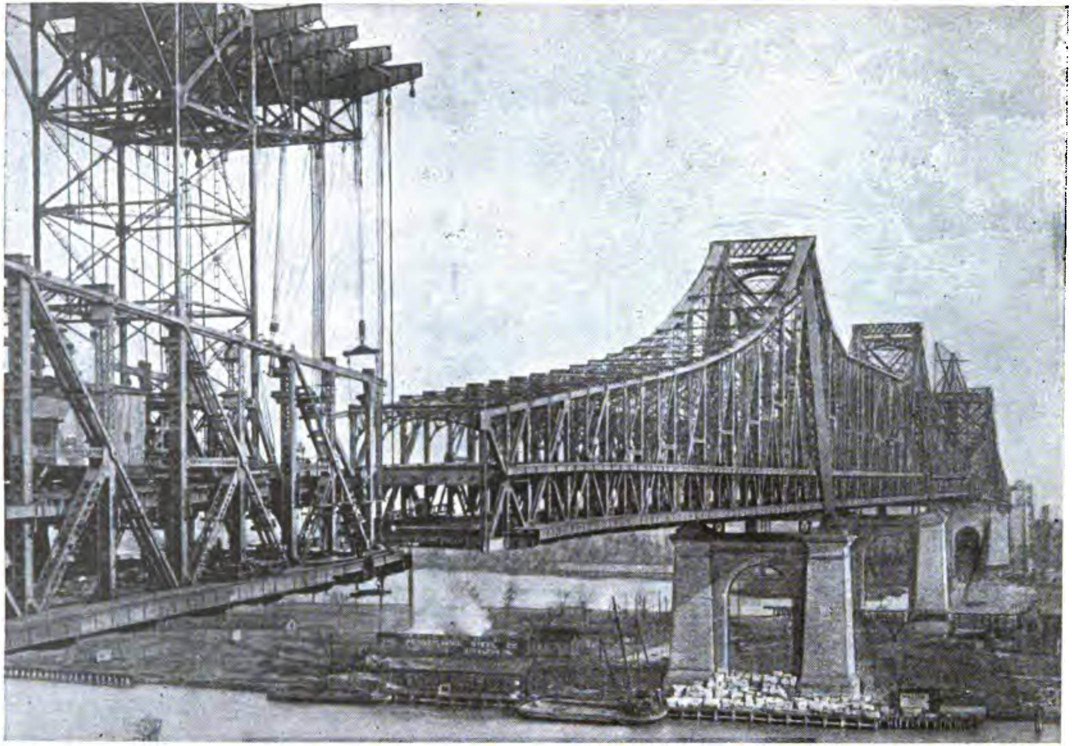


Fig. 109.—Cantilever arms almost joined. Traveller in foreground.
(Photo, The Pennsylvania Steel Co.)

HELL GATE ARCH BRIDGE.

"Oh!" says the poor writer, compelled to say "no" to many another bridge which clamors for mention, "there's a big number of you, I know—the Tower Bridge at London; and the Niagara Suspension, and the Niagara Cantilever; and the St. Louis Bridge; and great bridges in India, Siberia, Germany, France. Yes, I know it; and I haven't forgotten the steel arch over the gorge down which the Zambesi thunders, below the Victoria Falls, and the three-mile bridge that the Tay glides beneath. I wish I had space for you all, but it's honest truth, I haven't."

So it may seem unfair to look forward into the future, when the Pennsylvania Railroad Co. will bridge the East River at that spot known by the ill-omened name of Hell Gate with a mammoth steel arch to carry four railroad tracks. The plans for this bridge show a steel *arch* of 1,000 foot span—think of it!—between abutments. These abutments —I now quote *The Engineering Record*—are monumental stone piles dividing the arch bridge proper from the steel viaduct that forms approaches to it. The tracks will be 140 feet above water, passing

through arches 130 feet higher. Some of the steel members will be 9 feet in maximum diameter and weigh a hundred tons.

For the benefit of those who are interested in "records" I supply the information that this, the largest arch in the world (when it is completed) threatens to devour 80,000 tons of steel, enough to build four of the largest battleships.

In concluding this chapter I conjure up the shade of that great general and old-time bridge-builder, Julius Cæsar. He stands by the East River and gazes spellbound at structures which cross it. At his elbow is the modern engineer, who, modest man though he naturally be, cannot resist the temptation to borrow Cæsar's famous words, and mutter, "I came, I saw, I conquered." The shadow answers not a word, but, with the gesture of one vanquished, fades into invisibility.

Chapter X.

A TERRIBLE DISASTER.

The Quebec Bridge—Its huge span—Measurements—Erection—An ominous occurrence—The fall of the structure—A tragedy.

PASSING reference has been made to the Quebec Bridge, which will go down to history as associated with a dreadful calamity. This bridge, of the cantilever type, was designed to span the St. Lawrence near Quebec, and link up the Canadian Pacific and Great Northern of Canada railway systems on the north with the Grand Trunk, Quebec Central, and inter-colonial systems on the south of the river.

The most striking feature of the bridge was the great central span of 1,800 feet, made up of two cantilever arms each 562½ feet long, supporting a 675-foot centre girder. On the shore side of the towers two 500-foot arms extended to abutments on the river banks, to which they were anchored. The towers, with summits 400 feet above the river, had but two col-

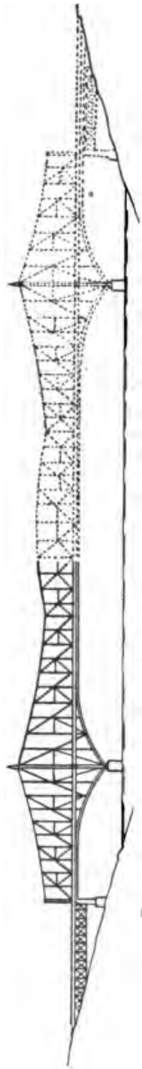


FIG. 110.—Diagram of Quebec Bridge. The completed portion, which fell on August 29, 1907, is marked in full lines.

umns each, resting on piers built at the edge of the water. The proportions of the structure will be gathered from the diagram Fig. 110.

The plans were the three years' work of a very eminent American bridge engineer, and had been carefully checked many times to prevent mistakes creeping into the calculations of the stresses which the various members would have to bear. The top chords of the cantilevers were made of great eye-bars, 76 feet long, 15 inches deep, and from $1\frac{3}{8}$ to $2\frac{1}{4}$ inches thick, joined by enormous pins of diameters varying from 1 foot to 2 feet. For each of the bottom chords and main compression members two web plates, $4\frac{1}{2}$ feet deep, and braced together by a lattice of angle irons, were used—in decided contrast to the great tubular members of the Forth Bridge.

The breadth of the roadway was to be 90 feet, to give room for two

railway tracks, two electric car tracks, and as many foot-walks and vehicle roads.

In 1902 work commenced on the erection of the steel superstructure. The anchor and river arms of the south cantilevers went up in 1905 and 1906, a vast 750-ton gantry "traveller" being employed. With the building season of 1907 began the building out of the suspended girder from the finished cantilever; and by the last week of August about 200 feet had been put together, making, with the cantilever arm, a projection of 800 feet from the south pier.

Then it was noticed that the bottom chord of the anchor arm was bending a little, and information was at once sent to the consulting engineer, but no orders came to clear the bridge of workmen till a thorough examination should have been made.

On August 29, just before work had ceased for the day, and while eighty men were still at their posts, the whole structure rocked and fell with a crash, hurling the men into the river or burying them under its ruins. Between sixty and seventy lives were lost. In a few moments 15,000 tons of steelwork, the results of three years' labor, had been reduced to a tangled mass of wreckage, reaching far out into the river.

Apart from the appalling nature of the human

tragedy involved, the collapse of the structure spread dismay among bridge-builders of the continent. The plans were based on theories found unreliable in practice. Investigation of the ruins tended to prove that the compression chords, whose warping had been observed, were unequal to the strain put upon them, and that to their final crumpling up must be assigned the origin of the disaster.

The Quebec Bridge will be built—of that we need have no doubt—but not before its design has been modified in several very important particulars.

Chapter XI.

THE DESIGNING OF DAMS.

Great quantities of water wanted for towns, power, and irrigation—Storage necessary—The dam-builder's task—Classes of dams—Masonry dams—The earth dam—Some mathematical facts—Centres of gravity and pressure—Further considerations—Distribution of pressure—Sir Benjamin Baker's model—Summary.

AMONG the most serious problems caused by the congregation of multitudes of human beings into great cities is that of providing these multitudes with an abundant supply of wholesome water, which is at least as necessary for their well-being as "the staff of life." Again, the advance of civilization demands more and more power to keep the innumerable wheels of industry moving, and no form of power is so cheap as that extracted from falling water. Once more, in many parts of the world the rainfall is so unequally distributed, both as regards its amount and the period during which it is precipitated, that only by storing the water when it is superabundant and

doling it out in the dry season can vast tracks of land be rendered fit for agriculture.

Consequently the engineer has been compelled to exercise his noble craft in impounding water in vast quantities. His usual method is to select a valley through which flows a stream of sufficient volume to be valuable. In the winter it may be a roaring torrent, in summer a mere trickle; but if its *average* flow is good, then it will serve. At a point where the sides of the valley close in and are steep he throws a dam across, against the upper side of which the imprisoned water piles up, until it reaches a height at which it is permitted to escape either over the dam itself or over a separate adjoining spillway. His task is beset with many difficulties, and is one requiring the greatest care, since the bursting of a dam is usually accompanied by black tragedy. But because dams, especially those for conserving potable (drinkable) water, are often situated in comparatively remote places, they attract far less attention than other accomplishments of the engineer. "The bridge across the Niagara gorge, a mountain railway, a great ocean steamer carrying thousands of tons of freight and moving under the influence of several thousand horse-power, more often fill our minds with thoughts of engineering

FIG. 111.—Excavating foundations for the Bradford Supply Reservoir Dam.

triumph than the silent and forgotten dam, far up some rocky gorge or spanning some mighty river, storing up for our use an element necessary for our very existence. None the less, however, is credit due to the man through whose intelligence such a work was conceived, and by whose skill and energy it was carried out."*

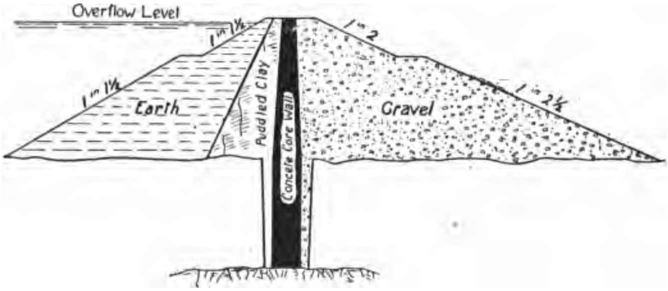


FIG. 112.—Section of earth dam with concrete core.

CLASSES OF DAMS.

Large dams may be divided into two main classes —(1) earth dams; (2) masonry dams. A section of an earth dam is given in Fig. 112. It is essential that a dam, whatever its type, shall be impervious to water; and in this case the engineer puts his trust in a masonry core (marked black), which reaches downwards to rock, to which it is firmly bonded. Being

*Cassier's Magazine.

comparatively thin, it would be broken by the water if unsupported, so on both sides are laid sloping heaps, the water face being protected by earth rammed down hard in layers, and puddled (rammed) clay—itself water resisting, provided it does not dry sufficiently to crack—and on the down stream side by a bank of earth or gravel. The slopes of the embankment must be such that the materials used shall have no tendency to slip. The angle made by the face of the slope with a horizontal line must not be greater than the "angle of stability" of the substance. If you pour sand slowly out of a bucket you will notice that the stuff forms a conical mound, which spreads in proportion to the increase in its height; and try as you may, you cannot coax the sand to exceed a certain steepness of slope. Its "angle of stability" is against you. We shall have something more to say on this subject when we come to discuss railway embankments and cuttings.

A well-made earth dam with masonry core is staunch enough to be widely used for moderate heights. When a great depth of water has to be impounded the engineer prefers

THE MASONRY DAM.

Now, it may seem to you to be a very simple thing

to build a wall across a valley. "All you want is enough stones and mortar for the job." True, and not true. You certainly must have the right amount. The difficulty is to calculate this amount, and to dispose it in such a form as to give you the best results for your money, and make everything quite safe.

Let us examine the facts of the case, and try to get some definite ideas on the proportioning of a dam. You will have to think rather hard perhaps to follow me, but I will endeavor to be as simple as possible.

First of all, let us consider the question of water pressure against a vertical face—say the side of a tank. The pressure increases with the depth. It is, speaking roughly, about 1 lb. to the square inch 2 feet below the surface of the water, 4 lbs. at 8 feet, and so on. If AB (Fig. 113) represents the side of the tank, and we draw on AB a right-angled triangle ABC, having the side AB equal to the side BC, then that triangle will represent the total water pressure on AB.

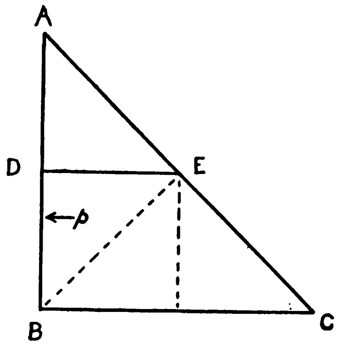


FIG. 113.—Diagram to show increase of water-pressure in proportion to depth.

In order to find what part of the pressure is borne by the upper half of AB a line, DE, is drawn parallel to BC through D, half way up. The quadrilateral DBCE can be divided into three triangles, each equal in area to ADE, therefore AD has to withstand only one-quarter of the total pressure.

Now let us go to actual figures. Assuming that AD is 1 foot high, the pressure would vary from nothing at A to ½ lb. to the square inch at D, giving an *average* pressure of ¼ lb. to the square inch. Taking DB, the pressure now increases from ½ lb. at D to 1 lb. at B, with an average of ¾ lb. to the square inch. So that it is evidently correct to represent the pressure by a triangle of the kind described above.

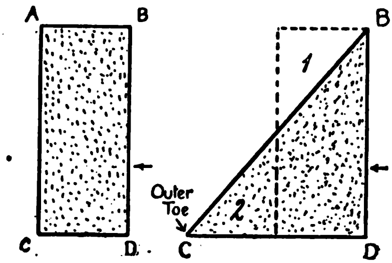
We may now go a step further, and consider how we can best shape our dam to withstand a column of water pressing on one side.

A wall, ABCD, with both sides vertical, as in Fig. 114, is perhaps most easily constructed. But since it is as thick at the top as at the bottom, whereas the water pressure increases steadily downwards, there seems to be a great waste of material somewhere. So we remove a part (1) from the top (Fig. 115) and place it at the bottom, to form a dam of triangular section BCD. This is more what we want, as the thick-

ness of the dam increases downwards in direct proportion to the pressure that has to be withstood.

CENTRES OF GRAVITY AND PRESSURE.

So far we have been considering the tendency of water to thrust the dam horizontally in front of it.



FIGS. 114, 115.—Rectangular and triangular dams, showing transference of position of part of the mass.

This may be partly prevented by putting an obstruction at the "toe" C. But we shall not even so necessarily escape the danger of the dam being lifted behind and *overturned* on that toe. The question arises, Which is better fitted to withstand the overturning—the oblong section dam ACDB (Fig. 114), or the triangular section dam BCD (Fig. 115)?

To answer this we must first think where the centre of gravity lies in each case. To find the centre of gravity of ACDB we draw lines from A to D and from

B to C; and in the triangle BCD we join C and D to the centre of the sides opposite (Figs. 116 and 117). The points at which the two lines cut one another in

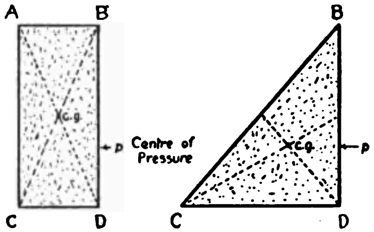


FIG. 116, 117.—Showing how to find the centre of gravity of a rectangular and of a triangular dam.

each case is the centre of gravity. Now, neither ACDB nor BCD will topple over when raised on one toe so long as the centre of gravity lies vertically over the

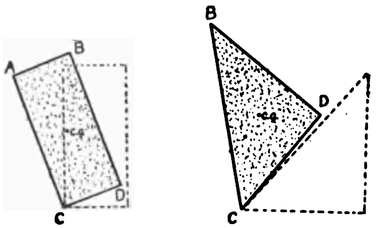


FIG. 118.—Dams tilted. The triangular dam has to be raised further than the rectangular dam for its centre of gravity to lie vertically outside the base-line.

base. In Fig. 118 we see both raised almost to the toppling point. It is evident that the triangle gains stability by having its centre of gravity so far back

towards the water. The water has had to raise it much farther than ACDB.

With regard to the "centre of pressure" mentioned in the heading of this section. The total pressure of water on a vertical face may be regarded as being concentrated into a single thrust on a point *p*, *one-third* of the way up the face, called the centre of pressure. This point is at the same level as the centre of gravity of the triangle BCD (Fig. 116), but below that of the oblong ACDB. So the triangle is once more seen to be the better form for a dam.

I scarcely need, perhaps, to point out the reason for opposing the vertical face of the dam to the water. I have before me a wooden block of a section like that of BCD. After marking the faces BD, BC, one-third of the distance from the bottom, I apply the point of a pin to the marks in turn and push horizontally, while supporting the farther toe with the edge of a ruler, so that the block shall not slip bodily. I find that the pin penetrates the side BD more deeply than the side BC before the block begins to lift.

FURTHER CONSIDERATIONS.

The sectional shape of a dam is necessarily influenced by the nature of the materials of which

the dam is built; but, speaking generally, its section is, for the reason given above, roughly that of a right-angled triangle with the sloping face down stream. The water face has a slight "batter" or inward slope, in order to relieve the inner toe somewhat. See Fig. 124, which shows a section of the famous new Croton Dam, described in our next chapter.

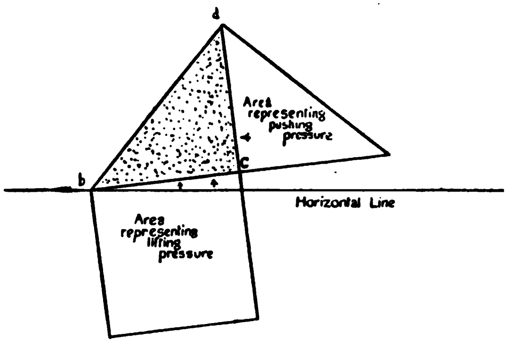


FIG. 119.—Diagram to illustrate the lifting-pressure of water.

If given a chance, water will exert an upward as well as a horizontal thrust, and the overturning of a dam is made easier.

Suppose that water penetrates under the masonry, as in Fig. 119; then the upward pressure on *every* square inch is that of the full depth of the water. To resort to figures. Supposing *b c* to equal *d c,* the pressure will be respectively proportional to a square

and a triangle—that is, the pressure on $b\ c$ is double of that on $d\ c$. Also, it is exerted in a direction most dangerous to the stability of the dam.

Hence engineers take the greatest pains to key the lowest foundation firmly to its bed, and to prevent the formation of any horizontal cracks in the masonry.

The distribution of pressure on the base of the dam is *not* the same when the reservoir is full and when it is empty. In the second case the weight at various points is proportionate to the height of masonry above, and the engineer has to avoid the crushing of the foundation by putting too much weight on any one part. When the water is at full height the centre of pressure in the dam is thrown forward towards the outer toe, and the engineer must be careful not to overload the foundations towards the toe.

The late Sir Benjamin Baker illustrated the stresses in a dam by making a jelly model of dam and foundation rock, and drawing lines at right angles across its transverse section, to divide it into squares. Pressure being applied at the back to represent the water thrust, the yielding jelly became distorted, and the inner toe pulled the "rock" upwards while the forward toe pushed it down (Fig. 120).

To sum up this chapter and set out the things which the builder of dams has to do:—

1. To get a firm foundation.

2. To bond the masonry to it in such a manner that it may not be pushed forward or admit water beneath it.

3. To rear on the foundations a dam of such section

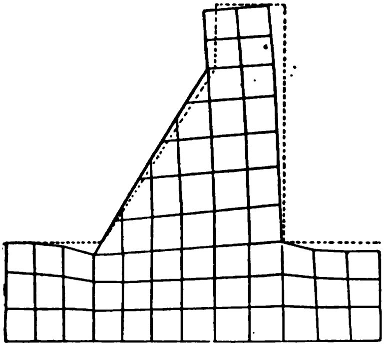


FIG. 120.—Jelly model of dam distorted by pressure, to show stresses in a dam and its foundations.

as best to resist overturning, while requiring the least quantity of masonry consistent with allowing a reasonable "factor of safety." The section has been shown to be roughly that of a right-angled triangle, with the right angle at the inner toe.

Now we may allow ourselves a glimpse at the fashioning of some of the greatest dams that have as yet been erected.

Chapter XII.

THE BUILDING OF THE NEW CROTON DAM.

The growth of New York's demand for water—The new dam; its great size—The Croton River—Plan of operations—Diversion canal—Removing débris—Cutting the foundations—Dam originally partly an earth dam—Laying the masonry—Stopping springs—Work in cold weather—The earth dam; grave doubts about its safety—Its removal decided upon—The spillway—Clearing the reservoir area—"Pointing" the dam—The dam completed.

MORE than sixty years ago the water supply of New York proved insufficient for the needs of the population, and the Croton River, some thirty miles distant, was laid under contribution. In 1843 a dam was thrown across it a few miles above its confluence with the Hudson, and a lake was formed of 2,000,000,000 gallons capacity. Subsequently the tributaries of the Croton River were dammed, one after another, to collect water that might be discharged into the lake when it became depleted.

But still the needs of the city grew, and by 1890 the supply had fallen far short of the demand. It was

therefore decided to build a dam some two and a half miles below the Old Croton, of such a height that the cubic contents of the lake should be increased sixteen-fold, and its depth be sufficient to completely submerge the original structure.

The dam has a length of about 1,200 feet, and a maximum height of 300 feet from rock to crest. This makes it the highest dam in the world. It contains over 800,000 cubic yards of masonry, and so comes next to the Pyramids among masonry structures. Its great bulk is due to the fact that, owing to the rock on which it is built being rotten, the foundations had to be carried in places to a depth of 130 feet below the river bed—that is to say, more than two-thirds of the entire mass are underground.

The Croton River has an average flow of about 15,000 cubic feet a second. Before any work could be done on the dam itself it was necessary to divert the stream through an artificial channel of sufficient size to pass the heaviest floods. Fig. 121 shows the plan of operations. A diversion canal, 1,000 feet long and 2,000 feet broad, was excavated in the rock of the right-hand bank, and strong retaining walls built, besides two large temporary dams reaching across the old course of the river, which is indicated

in dotted lines. Protected by the walls, the workmen began to excavate a huge trench with picks, spades, and steam shovels. The earth was removed to the adjacent spoil-banks at first by horses and locomo-

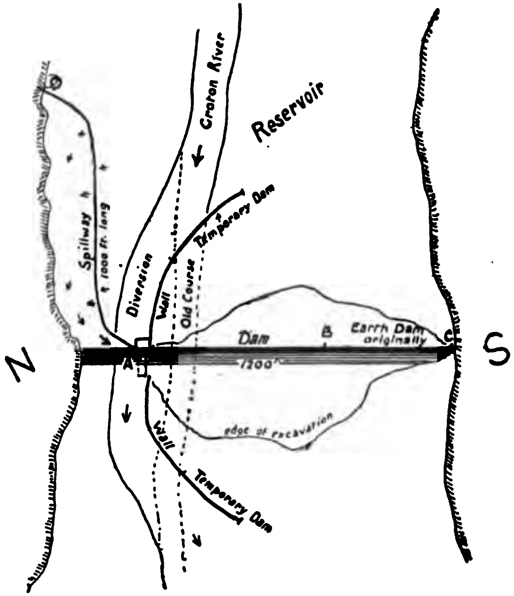


FIG. 121.—General plan of operations, New Croton Dam.

tives, then by stationary engines hauling laden trucks up inclined planes. When the slopes became too steep to render this method of transport economical, three cable ways, 2,000 feet long and 50 feet apart (Fig. 122), were slung across the valley parallel to

the axis of the dam, and nearly 300 feet above the lowest point of the excavation. Skips were run out along these and lowered to the working parties, filled, raised, drawn over the spoil-banks, and tipped. Very slowly the vast open cut yawned wider and wider till it reached rock. This last varied so greatly in soundness that it was found necessary to cut down very many feet further than had been allowed for in the original plans. The bed-rock contained numerous vertical fissures which could not be filled or left unfilled, for, as we have seen, leakage under a dam may have very serious results; and because every extra foot of depth to the dam meant an increase in width as well and a widening of the open cut, you will be able to understand that the actual cost of the dam far exceeded the first estimate.

Referring to Fig. 121 for a moment, you will notice that the dam is apparently solid from end to end. As a matter of fact, at the point A there is a large arch, under which the water discharged over the spillway flows into the old river channel below the dam. Therefore the dam proper terminates at A towards the north. If the spillway built on to it be included, the total length of the mass is somewhat over 2,000 feet. I must now mention that the portion

Fig. 122.—The Diversion Canal, New Croton Dam Works.
(Photo, "Engineering.")

of the dam between B and C (about 570 feet long) was begun and partly completed as an embanked core dam of the type illustrated in Fig. 123. It was to be 30 feet wide at the top, with a slope of 1 in 2, giving it a base width of 650 feet. The core wall would be 6 feet wide at top, and increase to 18 feet at a point 136 feet lower, and thence have parallel sides to the bottom. It was intended to give it a maximum height of 200 feet at its junction with the

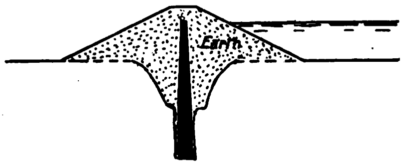


FIG. 123.—Section of the earthen portion of the New Croton Dam; afterwards removed.

masonry dam at the foot of the southern slope of the valley. We shall have more to say about this section of the dam a little further on.

LAYING THE MASONRY.

During excavation the men encountered at foundation level caves in the rock, one of them measuring 8 by 9 by 30 feet. These were built up with rubble masonry, and cement was forced into any cracks that

might exist. *Rubble* masonry, be it understood, is masonry constructed of unsquared stones, irregular in shape and size, as opposed to *ashlar,* in which squared stone is used. It is customary to face rubble-work with ashlar, as the straight joints of the latter can be made staunch more easily.

When a satisfactory foundation surface had been obtained, it was scraped with wire tools, roughened,

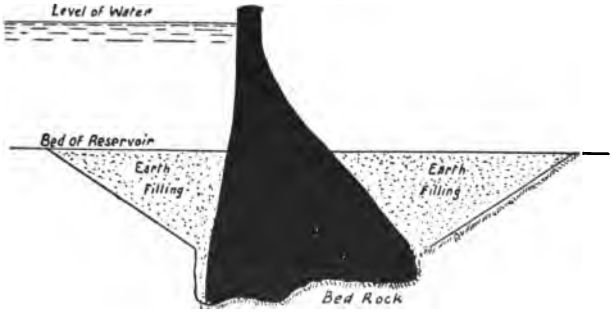


Fig. 124.—Section of the New Croton Masonry Dam.

washed scrupulously clean, and coated with best Portland cement. On this, the point of junction between nature's and man's work, no care was spared. You may picture to yourself the busy gangs, laboring in a pit protected from the river passing above them, preparing the great expanse of rock as thoroughly as a conscientious house-painter prepares the surface of a door or window frame before he applies his brush.

For every stone, whether it scaled five tons or a hundredweight, a bed of mortar and concrete was prepared most thoroughly. All stones were laid convex face upwards, so that no air might be included. To ensure contact between bed and stone, the workmen raised and lowered the stone two, three, four, or more times until all hollows in the cement had been detected and filled in. Spaces between the large stones were occupied by smaller stones set with similar care, so that no two stones should touch one another. Into every crack the men rammed cement with special tools.

The work was expedited by great steel piles built into the masonry as it rose, and made to serve as the supports of derrick cranes. This method largely obviated the need for independent cranes, and was found so satisfactory that engineers will probably employ it on other structures of the same kind.

At many points the men encountered springs, often of small volume, but in no case to be despised. They could be checked and rendered harmless in the following manner. Over the spring was built a masonry box, from which projected a vertical three-inch pipe. As the growing height of the masonry required, length was added to length, until the level was reached beyond which the water would naturally

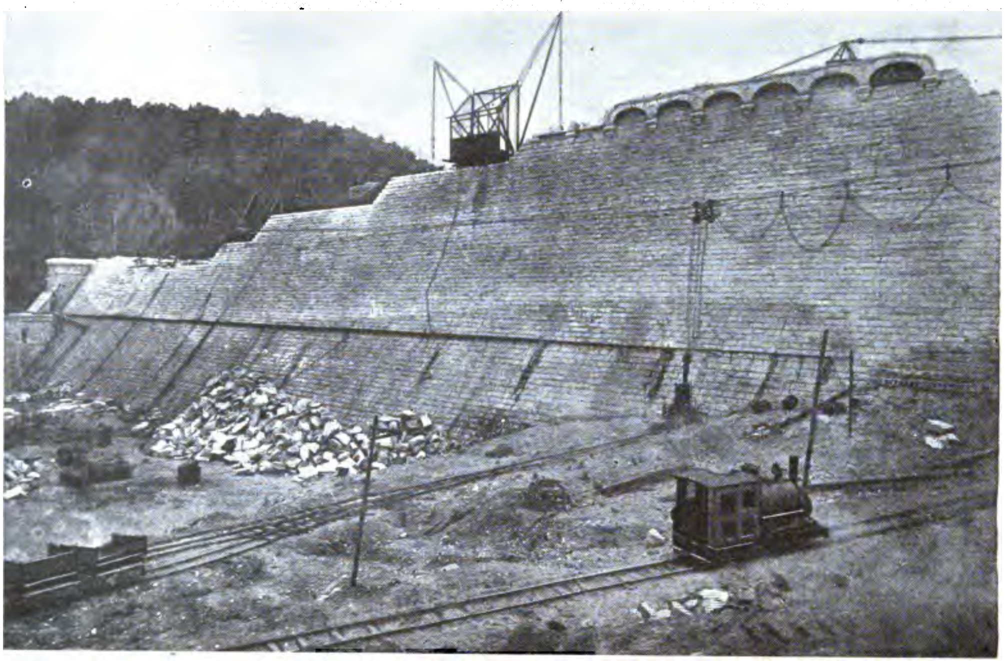


FIG. 125.—Building the New Croton Dam.
(*Photo, "Engineering."*)

rise no further. Liquid cement was then forced into the pipe under great pressure to replace the water, which, being entirely excluded from the stone work, had to retreat to the place whence it had come. In this way water pressure between the courses (we noticed its dangers in the last chapter) was entirely prevented, so far as these springs were concerned.

The work of building progressed in cold weather as well as in hot, for New York waited impatiently for an increased supply of water. Now, severe cold is one of the mason's enemies, as it plays havoc with his mortar if given the opportunity. Therefore, when the thermometer sank to freezing-point, all the sand used in the cement was piled over steam pipes to get thoroughly warm before being mixed with water and the other ingredients; the water itself had salt dissolved in it to lower its freezing temperature; and the stones were heated thoroughly by playing on them with steam jets. At night the surface of the masonry had to be protected carefully with matting.

THE EARTH DAM.

Four years after the commencement of operations on the dam—that is, in 1896—the aqueduct commissioners decided to extend the stone dam 110 feet fur-

ther southwards than the plans allowed for. The balance amount of earth dam was proceeded with, and a large part of it completed by the spring of 1901, when some ominous cracks appeared in the core wall. The gentleman holding the post of chief engineer at this period concluded, to use his own words,* "that there was a fundamental weakness here, and therefore it would be unsafe to proceed with the work. Close study brought to view objectionable points of the embankment and core wall, the most conspicuous of which were three: First, the excessive height, narrow base, and unstable foundation of the embankment; second, the great height of the core wall; and, third, the double means afforded the water to reach the core wall." Enlarging on the first of these features, he points out that the Amawalk Dam, impounding one of the upper Croton reservoirs, while only 85 feet high, as compared with the 200 feet of the New Croton, has an even wider base. With regard to the foundations of the embankment, it was a refilled pit (see Fig. 133), in which settlement would certainly occur sooner or later. Such a settlement must seriously imperil the core wall, to which, to make things worse, water would have access through the embankment

* *The Scientific American Supplement*, August 13, 1904.

itself, and at the point of junction with the main dam. At this point it was absolutely impossible to keep water out, even if the embankment were thickened indefinitely.

So the fiat went forth that the core wall must come down. It required some pluck on the part of the engineer to urge so drastic a course, but events proved that he was entirely justified in the position which he took up. For he tells us: "In March, 1903, the core wall having been removed, it became apparent that the embankment and core wall would have been undermined and destroyed if completed under the original plan. The core wall was found to be resting upon limestone that in places was completely disintegrated to the form of loose sand, and other portions in the process of disintegrating were more or less hard, the softer part being in such a condition that it could be easily crushed by the hand to the form of sand, and would absorb water as freely as a sponge." One shudders to think of the possible consequences had the earth dam been allowed to remain. Imagine 32,000,000,000 gallons suddenly let loose! The history of dam-bursts makes sad reading, and had other counsels prevailed, the Croton Dam might have added a terrible chapter.

However, down came the wall, and the thousands of tons of earth that had been dumped into the open cut on either side of it. The disappointed citizens of New York were grievously vexed by the prospect of additional delay and a corresponding excess in the cost of the dam. But the engineers went right ahead, widened the foundations, and carried the masonry dam across to the south slope, in which it is firmly embedded.

FIG. 126.—Section of spillway, New Croton Dam.

Simultaneously with the dam had risen the spillway shown sectionally in Fig. 126. It was built of great granite blocks, some weighing 10 tons each, bolted together by iron bars, so firmly embedded that it took a pull of 60 tons to dislodge some submitted to a test. The outer surface of the spillway is a series of steps, designed to break the fall of the water and protect the channel below.

Early in 1905, when dam and spillway had reached a certain height, the diversion channel opening in the dam was quickly blocked, and the water allowed to rise till 1,000,000,000 gallons had been stored, cover-

ing a wide expanse of hitherto unsubmerged country. The clearing of this area was a great work in itself, including the removal of three villages, numerous isolated buildings, cemeteries, farm premises, to say nothing of the transference of roads, railways, telegraph lines, and bridges. In addition, 75 miles of stone wall had to be built round the area required for the reservoir.

Since the water was more or less contaminated, it was drained away. The masons rigged up platforms to float against the upstream surface of the dam, so that as the water sank at a rate regulated to suit the work they might " point " the masonry on the outside.

After fifteen years of continuous labor, engaging upwards of 1,000 men, the dam was finished; and it now retains a body of water which assures a daily supply of 300,000,000 gallons to New York. The lake behind the old Croton Dam was 6 miles long; the new lake is 19¾ miles from end to end, and so deep that when the water rises to its full height the old Croton Dam is submerged 34 feet. The new dam has a maximum height of 297 feet and a maximum width of 216 feet; it contains 833,000 cubic yards of masonry; required 1,500,000 cubic yards of excavation; and cost $7,500,000, a large part of the outlay

being due to the alterations in plan and the execution of a vast amount of work which had to be undone afterwards. From the financial point of view the structure was a very expensive one; as an engineering feat it is remarkable. The slopes just below the dam have been grassed down and laid out artistically and a fountain constructed to delight those who visit the spot; and a power-house has been set up some distance below to convert the stored energy of some of the surplus water into useful electricity.

Chapter XIII.

HOW THE NILE WAS CURBED.

The valley of the Nile—The Delta Barrage—A failure—British engineers to the rescue—Further schemes—A great survey—The Assyut Barrage—Sir Benjamin Baker's account—Diverting the main channel—The great dam at Aswan—Original plans—A straight dam decided upon—The course of operations—Forming *sudds*—Pumping out the water—Rapid construction—The lock gates—The sluice gates—Raising the dam.

FROM a mountain stream we turn to one of the mightiest rivers of the world, the Nile, the great benefactor of the Egyptian valley through which it flows. In Egypt water does not come from above as in most other countries, but rises from below—that is to say, there is no rainfall; and agriculture has in the past depended for its very existence on the yearly flood caused by the melting of the Abyssinian snow, when the river overflows its banks, and covers the lower parts of the valley, leaving behind it, as it subsides, a thick and rich alluvial deposit. This natural irrigation is replaced during the dry season

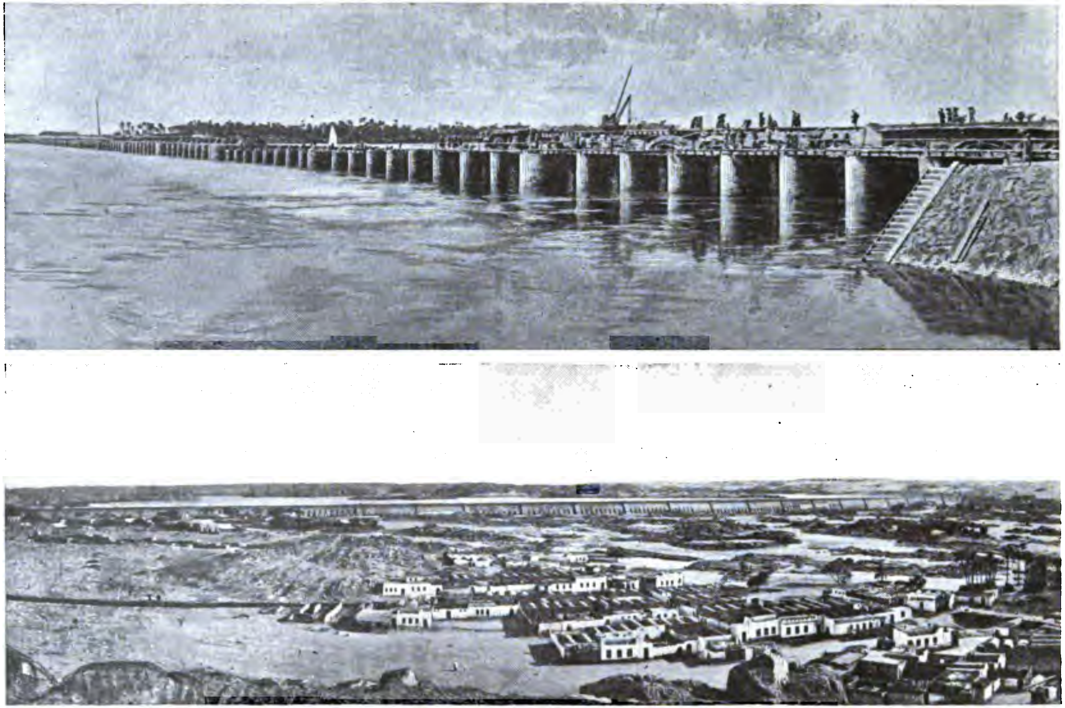


FIG. 127.—General view of Assyut Barrage (top) and Aswan Dam (bottom).

by artificial irrigation of a far less effective character, owing to the difficulty of raising large volumes of water to a sufficient height to be distributable over a wide area. In some years the Nile sinks so low that even the laborious raising of the precious liquid with the rude pole and bucket machine, which probably dates from the time of the Pharaohs, has to be controlled.

Hardly a century ago, perennial irrigation was first attempted by cutting deep canals to convey water to the land at "low Nile." Unfortunately these canals, inundated at "high Nile," silted up and had to be cleared by the wretched *fellahin* at the cost of great cruelty and oppression. The system failed.

There came to Egypt in the forties some French engineers, who said that the obvious thing to do was to save some of the flood's superabundance against the drought season by building a "barrage" across the Rosetta and Damietta branches of the Nile just below the apex of the Delta. A barrage, you must understand, is a weir or dam intended to raise the water level by but a few feet. The engineers accordingly constructed two long brick arch viaducts, containing 132 large sluices, which were to be completely closed in the summer months, to head up the water some

15 feet and throw it into the main irrigation canals below Cairo. Fifteen years elapsed between the commencement and the completion of the work, and when at last the engineer in charge closed the sluices the whole barrage began to slide down stream. Its foundations were insecure! So the sluices were opened again hurriedly, and it was feared that a million sterling had been wasted.

Presently English engineers appeared on the scene, examined the masonry, and issued reports to the Government. One report advised its entire removal; but Sir Colin Scott Moncrieff declared that he could underpin the foundations and make them quite firm for half a million sterling. His offer was accepted, and he carried out the work in the most masterly manner. At a later date subsidiary weirs were constructed below the barrage to relieve it of some of the pressure by banking up the water downstream. The plan adopted for forming the weirs, and found successful, was to make contiguous solid blocks of masonry under water in a timber caisson that was moved across the river.

The barrage greatly improved the irrigation of the Delta, but brought little relief to the higher reaches of the Nile valley. Other constructions of the same

nature were so urgently needed that Lord Cromer commissioned Mr. William Willcocks to survey the whole valley, and ascertain the points at which the Nile could be dammed. Mr. Willcocks, accompanied by a faithful Nubian, tramped the country for three

FIG. 128.—Water passing through the sluices of the Aswan Dam.

years, at the end of which he drew up a long report, recommending a barrage at Assyut, 250 miles above Cairo, and a big dam at Aswan, 350 miles further upstream. His estimates of cost, however, were so high that for want of the necessary financial support

the carefully executed plans had to be "pigeon-holed," to await the day when they might be carried into execution.

Luckily, soon afterwards, some capitalists and contractors expressed their willingness to invest money in the scheme, and to agree to repayment being spread over a long term of years. The contract for the barrage and dam fell to Sir John Aird and Co., who commenced work on both in 1898.

THE ASSYUT BARRAGE.

Near Assyut, the thriving capital of Upper Egypt, lying in a fertile plain at the foot of the Libyan Mountains, the Nile contracts to a width of about half a mile. At this point a barrage, closely resembling that already described, was constructed in three and a half years—in a year less than the stipulated time. Its total length is 2,750 feet, or rather more than half a mile, and it includes 111 arched openings of 16 feet 4 inch span, which can be closed by steel sluice gates 16 feet high. Its purpose is to improve the present irrigation of Middle Egypt and the district called the Fayoum, and to bring about 300,000 more acres under cultivation by throwing water at a higher

Fig. 129.—The upper illustration shows the closing of a *sudd;* the lower shows the water impounded by complete stone and sand-bag *sudd.*

level than formerly into the great Ibrahimyah Canal, whose intake is immediately above the barrage.

The following is in substance the account of this great undertaking as given briefly by the engineer responsible for its design, the late Sir Benjamin Baker, in a paper read before the Royal Institution of Great Britain.

The piers and arches are founded upon a platform of masonry 87 feet wide and 10 feet thick, protected up and down stream by a continuous watertight line of cast-iron sheet piling, with cemented joints. This piling reaches down into the sand bed of the river to a depth of 23 feet below the upper surface of the floor, and thus cuts off the water and prevents the undermining which had given so much trouble in the case of the Cairo barrage. The floor is further protected along both edges by aprons of clay and gravel faced with stones. The roadway running along the crest is 41 feet above the platform, and each pier has an up-and-down-stream length of 51 feet.

"It is easy enough," wrote the author, "to construct dams and barrages on paper; but wherever water is concerned the real difficulty and interest is in the practical execution of the works, for water never sleeps, but day and night is stealthily seeking to

defeat your plans. On the Nile the conditions were very special, and in some respects advantageous. There is only one flood in the year, and within small limits the time of its occurrence can be foretold, and arrangements made accordingly. It would have been impossible to have carried out the Nile works on the system adopted had the river been subject to frequent floods. The working season for below-water work on the Nile lies practically between November and July, for nothing would be gained by starting the temporary enclosing embankments, or sudds, when the river was at a higher level than it is in November; nor would it be possible at any reasonable cost to prevent the sudds from being swept away by the flood in July. At Assyut the mode of procedure was to enclose the site of the proposed season's work by temporary dams or *sudds* of sandbags and earthwork, and then to pump out and keep the water down by powerful centrifugal pumps, crowd on the men, excavate, drive the cast-iron sheet piling, build the masonry platform and piers, lay the aprons of clay and stones, and get the work some height above low Nile level before the end of June, so that the temporary dams should not require reconstruction after being swept away by the flood. The busiest months were May

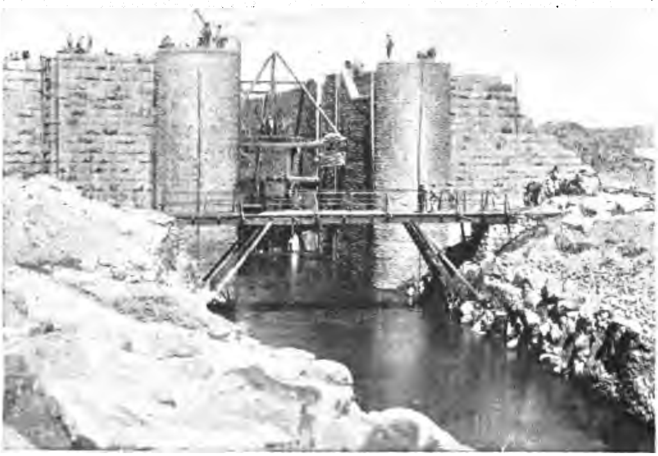


FIG. 130a.—A lock in course of construction at the west end of the Nile Dam. Observe its great depth.

FIG. 130b.—General view of the Aswan Dam, showing water impounded.

and June; in the year 1900 the average daily number of men was 13,000. It is then also hottest, the shade temperature rising to 118 degrees. To keep the water down, seventeen 12-inch centrifugal pumps, throwing enough water for the supply of a city of two million inhabitants, had to be kept going, and in a single season as many as one and a half million sandbags were used in these temporary dams. The bed of the river being an extremely mobile sand, the constant work of the pumps occasionally drew away sand from under the adjoining completed portions of the foundations, necessitating the drilling of many holes through the 10-foot thick masonry platform, and filling under pressure with liquid cement. About 100 springs burst up through the sand, each one of which required special treatment."

One of the most remarkable features of the work was the diversion of the channel of the river. For several years previously the main channel had shifted towards the eastern bank, leaving a large shoal on the western bank. During the construction of the west part of the barrage the shoal helped the engineers, but when the eastern part had to be taken in hand it became necessary to alter the course of the main stream, which they effected by forming great embank-

ments of huge stones from the east bank to the middle of the bed, so as to block the water on that side and compel it to scoop out a path through the shoal.

The barrage, which was completed in 1902, heads up the water to an extra depth of twelve feet. Just above the dam is the intake of the Ibrahimyah Canal, which follows the valley for a couple of hundred miles, and distributes water over many hundreds of thousands of acres. The Assyut structure is in fact the regulator of the water sent down from

THE GREAT DAM OF ASWAN,

built across the First Cataract. This place was selected by Mr. Willcocks because the river here is bounded by granite hills and has a rocky bed in which firm foundations could be secured. The original plans of Mr. Willcocks allowed for a curved dam which could bank up the water to a depth of 120 feet, and form a lake of 3,700,000,000 cubic metres. But because such an increase in depth would submerge the fine ruins on the island of Philæ, just above the site, it was decided to reduce the level to 67 feet, and the quantity impounded to about 1,200,000,000 cubic

metres. For the curved dam was substituted a straight one, 1¼ miles long, containing 180 sluices, closed by gates of the Stoney roller pattern, easily raised even when subjected to a water pressure of several hundred tons.

The task before the engineers was this: to build a great masonry mass, weighing some 500,000 tons, across channels through which the water rushes at a speed of 16 miles an hour with a turbulence almost, if not quite, equal to that of the Niagara Rapids.

The sketch map (Fig. 131) shows the five channels to which the flow of the river is confined at low Nile by the banks and rocky islands. Since the water must be allowed to escape at one place or another, it was impossible to block all these channels at once. So it was decided to attack the three easterly "babs" or "gates"—the Kebir, Haroun, and Soghair—first; check the water here, lay the foundations, then close the central channel, build across it, and finally dam the western channel after opening the eastern sluices in the partly finished dam.

Sir John Aird and Co. signed the contract for the dam in February, 1898. By the end of two months the hitherto unpopulated desert had been transformed into a busy town, with works, offices, machine-shops,

hospital, and accommodation for 20,000 natives and Europeans. To the credit of the contractors be it stated that they spared no expense to keep their employés healthy and comfortable. To take an instance: In view of the danger of sunstroke, tents were set up at many points, each containing a bath, ice-box, and a telephone. If a man succumbed to the heat he was

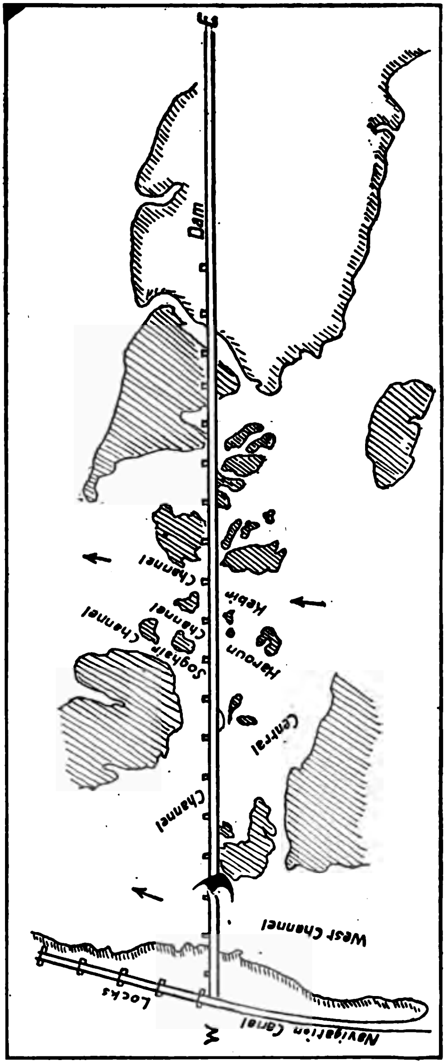


FIG. 131.—Sketch map of the Aswan Dam site.

hastily placed in the nearest iced-water bath to await the doctor who had already been summoned through the telephone. Consequently hardly a life was lost by sunstroke. What a contrast this treatment affords to the inhumanity that marred the making of the Alexandria Canal in the time of Mahomet Ali, seventy years earlier, when 20,000 miserable *fellahin,* torn from their homes to do unpaid labor, died in the trenches!

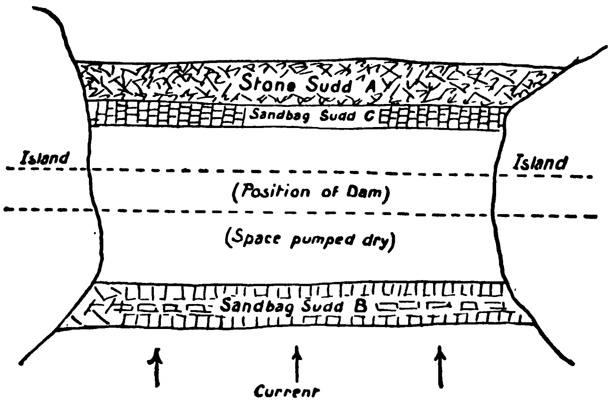


FIG. 132.—Showing how a channel was closed by *sudds.*

As at Assyut, construction could be carried on only under the protection of sudds. But the raising of watertight sudds in the torrents of Aswan was an infinitely more difficult matter than it had been in the first case. In Fig. 132 is given a diagrammatic

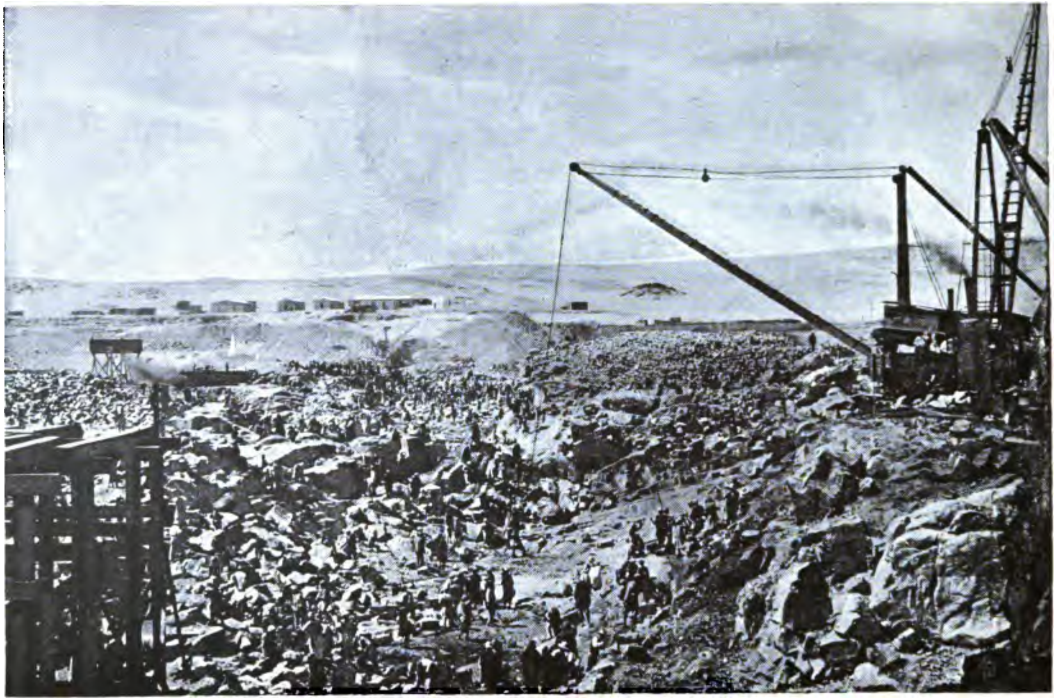


Fig. 133.—Excavating foundations for the Aswan Dam.

illustration of the manner in which the engineers went to work. To check the water and produce a comparatively calm pool, stones weighing from 1 to 12 tons each were flung into the stream, until a barrier, A, 30 or more feet high had been formed above water level, *below* the line of the dam. The violence of the current was so great that the engineers had sometimes to fasten several of the largest stones together with steel wire, rope them to a truck, and send truck and all flying into the gap. When a lodgment had once been obtained by these masses the completion of the sudd was a comparatively easy matter.

To fill the crevices between the stones large quantities of sand and cement were tipped on the up-stream side of the sudd. As soon as the barrier was staunch, a second sudd, B, of sandbags was formed *above* the line of the dam, and a second sandbag sudd below it. These last two were placed in each channel after the floods of 1899.

Early in 1900 began the exciting work of pumping out the spaces enclosed by the sudds and islands. The embankments proved to be so tight that the rock was soon exposed, and such leaks as existed were easily nullified by a couple of pumps to each channel. Then the workmen swarmed into the uncovered space,

FIG. 134.—The dam half built.

and with orderly haste cut away all rotten rock, which in some places required excavating nearly 40 feet deeper than the level shown in the contract drawings, and increased the width of the foundations from 70 to 100 feet. This was a serious set-back, since the masonry must be raised to above flood level before the next flood came. A thousand Europeans and ten times that number of natives were crowded on to the work, which for a month at least went on ceaselessly by night as well as by day, arc lamps giving light to the masons after sundown. In one day as many as 3,600 tons of masonry were placed, and with the great care required for work of this kind. The wiry Egyptians showed themselves no mean workers, and in a heat that was at times almost intolerable.

When Father Nile rose at the end of the year he was obliged to pass through a number of sluice-ways in the more than half-finished dam. Next year (1901) the western channel was closed, and work continued at the locks at the western end. The locks, four in number, are 270 feet long each, and 32 feet wide, and are provided with enormously strong gates which, instead of opening up-stream—as is usual—slide sideways into recesses in the masonry, being suspended on drawbridges lowered when the gate has to be closed

and raised when it is opened. At each end of the locks is a navigation channel cut in the rock of the bank to protect vessels from the strong current. Previous to the building of the dam the services of some hundreds of men were required to get even a moderately sized vessel up through the Cataract. The largest river steamers are now able to pass it, and travel 800 miles further south, to Wady Halfa.

In 1902 the dam was completed, and formally opened in December by the Duke of Connaught. Its maximum height is 130 feet, and its greatest (foundation) width—as we have already noticed—100 feet, tapering to 24 feet at the top, where a roadway runs between parapets.

Every year, when the river rises for the flood, all the sluices are opened, and the silt-laden water passes freely at the rate of 15,000 cubic metres per second. After the flood, as soon as the water becomes clear again, the sluices are closed gradually, and the water impounded until it is 67 feet deeper on the up-stream than on the down-stream face of the dam. During May, June, and July, the contents of the great lake, 150 miles long, are gradually doled out to the river below, and allowed to run down to Assyut, where it is directed into the irrigation canals.

THE SLUICE GATES.

The success of the scheme depended largely on the ease with which the sluices could be opened and shut,

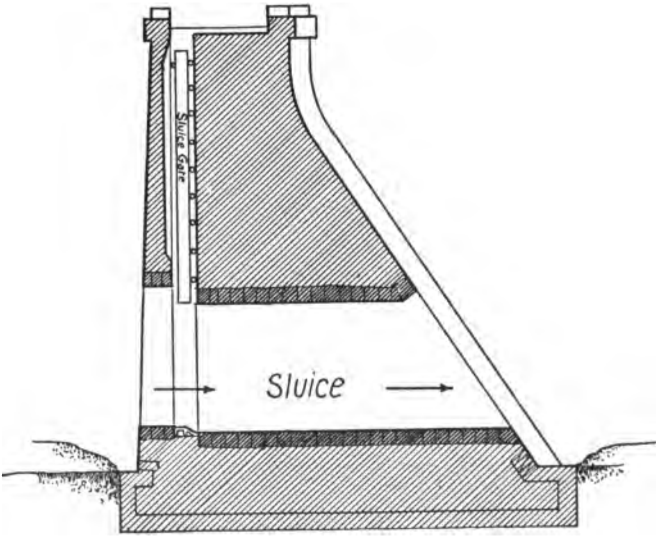


FIG. 135.—Section of the Aswan Dam at a sluice.

therefore some notice is due to the sluice gates used in the Aswan Dam and Assyut Barrage. Because the silt suspended in the water is extremely valuable to the agriculturist, the ordinary spillway used in town-supply dams would not suit, as likely to cause the

silt to be deposited behind the dam, and so it was essential that there could be sluices controlled by gates opening upwards. The Stoney gate is a large iron shutter working up and down in strong steel sockets built into masonry. Between the vertical edges of the shutter and the down-stream jambs on which they press are numbers of anti-friction rollers. (Fig.

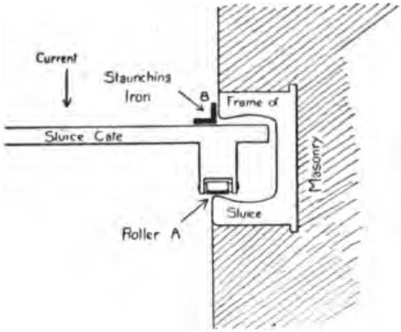


Fig. 136.—Diagram of Stoney sluice-gate, showing anti-friction rollers, A, and staunching-irons, B.

136, A.) As these prevent close contact at these points the water would have a way through were it not for the long vertical staunching rods of angle iron, B, hanging freely by their upper ends. The pressure of the water forces them into the angle between the face of the shutter and the frame, and ensures a tight joint. So effective is the principle that two men can

raise and lower one of the sluices, against a pressure of 300 tons, with a simple crab winch.

RAISING THE DAM.

Though the dam has proved of incalculable value, its height is insufficient to store all the water that Lower Egypt needs; in 1905 the reservoir was emptied completely and much land remained unirrigated. So in 1907 the work of raising the dam 23 feet and thickening it in proportion, to increase the storage *two and a half times,* was begun. The great difficulty that the engineers have to face is that of bonding the new and old masonry, as the old has cooled to a point which will not be reached by the new for some time to come. The extension will therefore be built as an independent mass, free to contract until it has the same temperature as the older work, and the two portions will then be joined by cement and steel rods.

This addition will entail an outlay of about £1,000,000, and occupy the contractors for five years; but to the credit side must be placed the reclamation of a million acres of desert capable of raising every year cotton crops worth some millions of pounds sterling. The Philæ temples will be submerged after all,

and much as that fact is to be deplored, it is still more regrettable that the decision to submerge them was not made nine years earlier, before the engineers began work at Aswan.

[*Note.*—The photographic views illustrating this chapter were kindly supplied by Sir John Aird and Co., of London.]

Chapter XIV.

SOME NOTABLE RESERVOIRS.

THE CATSKILL RESERVOIRS.

The Catskill Reservoirs—Olive Bridge Dam—The reservoir—Other great storage schemes—The Wachusett Reservoir for Boston—How Manchester, Liverpool, and Birmingham are supplied—An Australian dam—The Barren Jack scheme—An arch dam—Irrigation projects—The Periyar, Tansa, Nira, Khadakvaria, Marakanave, and Dhukwa dams—Irrigation work dams in the United States—A Mexican dam.

THOUGH the Croton River reservoirs discharge 300,000,000 gallons a day into the aqueducts, the demand far exceeds the supply, and the New York Water Board, foreseeing that the time is not far distant when the enormous quantity of 1,000,000,000 gallons will be needed daily, have taken steps to bring to the city an entirely new water supply, wholly independent of the resources of the famous Croton watershed.

About 80 miles N.N.E. of New York city lie the Catskill Mountains, abounding in splendid scenery

Fig. 137.—Six-foot mains through which water is pumped into the great reservoirs at Staines, near London.
(Photo, Messrs. Thos. Piggot & Sons, Birmingham.)

and intersected by deep ravines running between almost perpendicular cliffs. Some 900 square miles of this region is to be drained into reservoirs having a capacity sufficient to give a constant supply of over 600,000,000 gallons a day. Four streams will be impounded—the Esopus, the Rondout, the Schoharie, and the Catskill.

Work has already been begun on the damming of the Esopus at a place named Olive Bridge, where a dam nearly 5,000 feet long and of a maximum height of 220 feet will, in conjunction with two miles of dikes, enclose a lake 12 miles long and 2 miles wide, to be known as the Ashokan Reservoir. The lake will have four times the capacity of that formed by the New Croton Dam, and will contain 120,000,000,000 gallons.

As for the Olive Bridge Dam itself, it will be in three parts—a 1,000-foot central section of masonry, containing 1,000,000 cubic yards of masonry, and two end sections of core-wall earth dam, for which 6,000,000 cubic yards of embankment will be required; so that when completed, this huge mass will be the largest work of its kind in existence. An interesting feature of the masonry dam is a system of vertical expansion and contraction joints formed of

stepped concrete blocks able to slide over one another, their faces being dressed with a compound to render the joints watertight while not hindering movement. It is expected that the cracking which usually results from the cooling of large bodies of masonry work may thus be entirely avoided.

The reservoir is naturally divided (almost) into two basins, one in the valley of the Esopus, and the other in that of the Beaver Kill, which flows into the Esopus just above the Olive Bridge Dam. A weir, 2,200 feet long, partly of earth and partly of masonry, completes the division, and is of such height that water may pass from one basin to the other under certain conditions.

Round the limits of the Beaver Kill basin more than three miles of dike will be built; and for the overflow of the reservoir a 1,000-feet spillway is planned.

A description of the aqueduct leading the water to the city of New York is reserved for a later chapter.

OTHER GREAT STORAGE SCHEMES.

The Wachusett Reservoir, of 63,000,000,000 gallons capacity, and 6½ miles area, was formed by impounding the Nashua River, in Worcester County,

Massachusetts, by a dam 1,250 feet in length, 158 feet high (maximum), and 120 feet thick (maximum). It ensures to the city of Boston a daily supply of about 100,000,000 gallons.

The building of the dam was by no means the heaviest part of the work, for great dikes had to be constructed round the edge of the reservoir, and the whole of the area to be covered by the water cleared

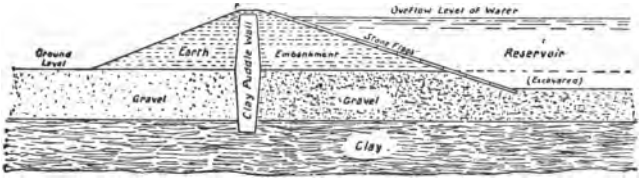


Fig. 138.—Section of earth dam, with clay puddle central wall, used for shallow reservoirs.

of trees and buildings, and its surface stripped of earth to an average depth of 10½ inches. The stripping alone cost $3,000,000, but the earth came in useful for the dikes referred to above.

In England the cities of Manchester, Liverpool, and Birmingham draw the bulk of their water from distant sources.

To increase the Manchester supply a dam was thrown in the early eighties across the outlet of Thirlmere, a lake in Westmoreland, to raise the level of the lake 40 feet, and store over 8,000,000,000 gal-

lons of water. An aqueduct, 96 miles long, connects Manchester with Thirlmere.

The success of the enterprise stimulated the citizens of Liverpool to do likewise. A suitable collecting ground was found among the hills of North Wales in the valley of Vyrnwy, a tributary of the Severn, which was closed by a dam 1,172 feet long, 161 feet high, and 127 feet thick at the base (maximum). Lake Vyrnwy, created by the dam, has an area of 1¾ square miles, and an average depth of about 70 feet. The dam, a fine piece of work, serves as a weir, over which all the surplus water falls. The supply is led to Liverpool through 69 miles of pipes, tunnels, and culverts, capable of passing 40,000,000 gallons daily.

Birmingham draws its main supply from the head waters of the Wye, in Radnorshire, Wales. A series of dams have been constructed across the Elan valley, enclosing an equal number of reservoirs, which resemble a flight of great water stairs, each level reaching to the foot of the dam above. Other dams will be added as required. The lowest dam, like the Vyrnwy, is a weir, and over it pours in flood time the finest waterfall in the kingdom. The Birmingham aqueduct ranks between the two already mentioned, being 74 miles long.

AN AUSTRALIAN DAM.

The greatest river of Australia is the Murray, which drains the western slopes of the mountains of New South Wales. One of its confluents is called the Murrumbidgee. This river rises almost in the south-east corner of the state, and about 150 miles from its source is swelled by the waters of the Yass and Goodradigbee. Like many—we might say most—Australian streams, it varies greatly in volume at different seasons. At times it overflows its banks and inundates the country far and wide, and at other times it almost disappears; but on the average its flow is sufficient to irrigate the great area of the desolate Riverina if its waters were stored.

The Riverina includes much land which, given a reliable water supply, could be much more closely settled than is possible at present. The Public Works Department has therefore decided to dam the river at Barren Jack, three miles below the infall of the Goodradigbee, and impound the three streams so as to form a lake having an area of 20 square miles, and a capacity of over 33,000,000,000 cubic feet, practically equal to the reservoir ponded by the original Aswan dam.

Nature has been kind to the people of New South

Wales in one respect—she has at Barren Jack confined the river to a gorge, with granite cliffs rising to a height of 1,000 feet, and only 300 yards apart. Here there will be built a large dam of a type that we have not yet noticed. This is the arch type, in which the dam is *curved,* its convex side turned upstream, so that the horizontal pressure of the water shall take the place of the vertical load on a bridge arch. As the thrust is transmitted to the abutments on which the ends of the dam rest (see Fig. 139), provided those abutments are very solid, a far smaller weight of masonry is required in an arch dam than in a straight dam. Consequently the arch dam is employed by preference in narrow gorges such as those in the Californian mountains, where several good examples may be seen—the most famous, the Sweetwater, 90 feet high and 340 feet long, "a narrow wall, bending upstream in a graceful curve, the slender outlines of which cause a feeling of distrust in the non-technical observer as to its competency to perform the duty of holding back the waters of the river." *

To return to the Barren Jack Dam. Its curve will be one with a radius of 940½ feet, and the foundations are to have a maximum width of base (160⅓

* *Cassier's Magazine.*

feet) sufficient to allow the masonry to be raised to a final height of 232 feet from rock to crest. The length of the arc is about 900 feet.

The structure will be of "cyclopean rubble"—that is, large blocks of granite set in cement. The rocks

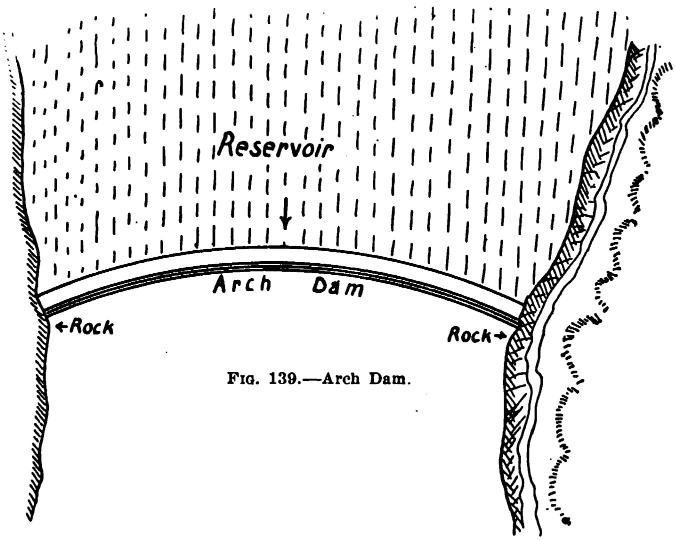


Fig. 139.—Arch Dam.

at the side provide an inexhaustible and convenient supply of materials (as was the case at Aswan), so the work will be carried through quickly.

To let off the flood-water it is proposed to cut two large culverts through the cliffs round the ends of the dam itself, and as outlet, a 14¼ by 13 feet tunnel

will be provided in the body of the main wall, controlled by valves worked from a separate masonry tower rising in the reservoir, and by a second set of valves near the down-stream face, operated from a chamber in the dam.

When the work is finished, and the masonry wall connects Barren Jack with Black Andrew, the brother cliff on the other side of the gorge, the water will pond 40 miles up the Murrumbidgee, 13 miles up the Goodradigbee, and 19 miles up the Yass, and there will be in the heart of the mountains an inland sea on which all the navies of the world could float comfortably. Flats will become broad lakes, and the hilltops will stand out as islands.

The water issuing from the reservoir is to pass down the existing river bed for 240 miles to Narrandera, where is the off-take, or entrance, of a large canal, already partly excavated, that feeds a network of subsidiary irrigation canals. A million and a half acres will benefit, at a cost of an equal number of pounds to the Government; and as Mr. Lee, the Minister for Public Works, aptly said, a district which has been described as " No Man's Land " will be converted into " Many Man's Land." That solitary dam promises to belie its name and to make a desert smile

for a quarter of a million settlers; and before many years have passed, it will be but one of a number built on the course of Australia's great rivers.

OTHER GREAT IRRIGATION DAMS.

Wherever there is an arid district occupied by a civilized people, and intersected by a river, there you will find schemes for water storage either completed, in course of completion, or planned for the future. It is impossible here to do more than briefly refer to some of the most notable projects which have not yet received our attention.

India has always been noted for its great irrigation works. The Periyar Dam, in Travancore, ponds the river of the same name to form a huge lake, which is diverted by a tunnel cut through the watershed into the channel of the Valgai River on the other slope, and expends itself among the irrigation canals of Madura. Then there are the Tarsa Dam, Mysore, over 1½ miles long, holding back a body of water larger than the Croton Lake; the Nira Dam, 3,000 feet long; and the Khadakvasia Dam, Poona, 1 mile in length. To the Indian list will soon be added the Marakanave Dam, in Mysore, fit to rank in point of retaining capacity, with the Aswan and Barren Jack

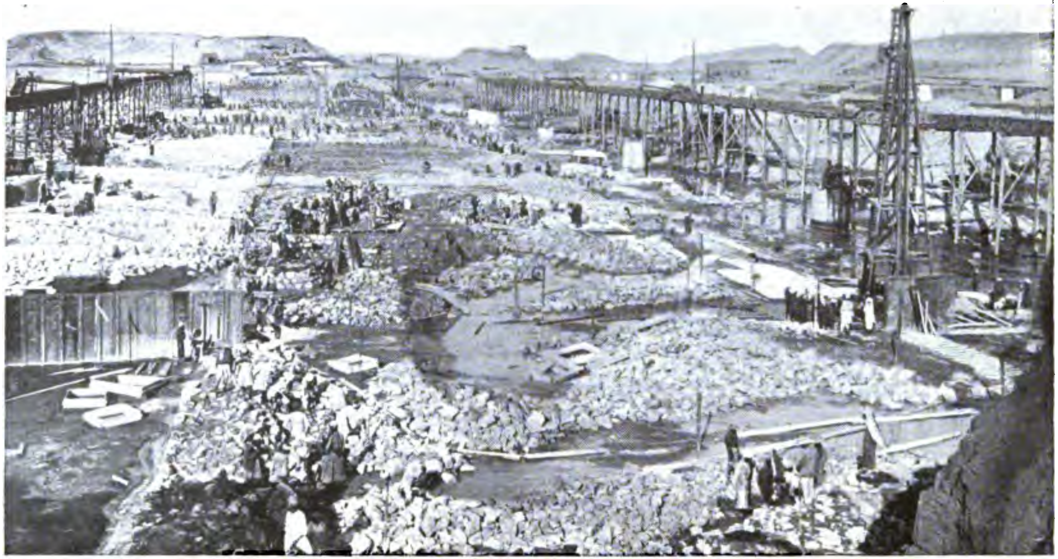


Fig. 140.—Preparing the foundations for the Isna Barrage on the Nile.
(*Photo, Sir John Aird Co.*)

enterprises; and the Dhukwa Dam, Bombay. All these great structures protect vast tracts of naturally rich country from the miseries of periodical drought.

In the United States great efforts are being made to reclaim the barren West; and every year sees thousands of acres of what was recently desert added to the agricultural area of the country. The Shoshone River is being curbed in a cañon by a dam 312 feet high; the Yuma, by one 4,700 feet long and 346 wide, built safely on an earth foundation. Nor must we overlook the enormous Roosevelt Dam in Arizona, destined to create an artificial lake of unprecedented capacity, or the Pathfinder Dam, Wyoming, to impound 3,840,000,000 gallons.

Mexico also is busy wresting land from the desert. Its most notable dam, the Jalpa, built a century ago, gave way during a flood, and the water swept away everything, living and inanimate, that it encountered. Four hundred people were drowned. The stream hurled huge blocks of masonry hundreds of yards, rooted up the trees, and caused desolation where it passed. The dam has been rebuilt by the present owner of the Jalpa *hacienda* [farm], Mr. Oscar J. Braniff, and may claim to be the biggest thing of its kind erected by a single private individual.

Chapter XV.

AQUEDUCTS.

Roman aqueducts—Their principle—The modern aqueduct—"Hydraulic gradient"—Balancing reservoirs—Siphons—Pipe-joints—Notable aqueducts—The New Croton described—The Catskill Aqueduct—A colossal enterprise—Enormous siphons—The Coolgardie pipe line—A novel kind of pipe—Laying the pipe—Pumping the water—Charging the main—Wooden pipe lines—Some striking examples—A clever piece of work, shifting a pipe-line—A curious excavating machine.

SOME of the most striking examples of ancient engineering which have survived the assaults of time are the aqueducts found in several European countries, Asia Minor, and Northern Africa. Most of them are the work of the Romans, who were as fully alive as we are to-day to the necessity of an abundant supply of fresh water for large towns.

These aqueducts, some more than fifty miles in length, lead the water on a slight and unbroken gradient (Fig. 141) from source A to point of delivery B. As the Romans were unacquainted with the use of large metal pipes able to withstand high pressures

they were obliged to bore through intervening mountains and bridge over valleys to maintain the correct decline required to carry the water at a certain speed. They naturally selected, as far as was possible, routes which avoided tunnelling and bridging; but when it became necessary to do either of these two kinds of engineering they showed themselves wonderful workmen, considering the rudeness of the tools and instruments with which they had to work. The ruins of the aqueduct bridges fill the beholder with admiration. Near Antioch, to take an example, is still to be seen such a bridge, 700 feet long and 200 feet high at the deepest point. At Mayence are the ruins of an aqueduct over three miles long, carried on 500 to 600 pillars. In many countries which the Romans once occupied you may see similar proofs of their constructive skill.

Though the bridgework formed so striking a feature of these old aqueducts, by far the greater part of the course was confined to stone and cement-lined channels cut in the earth and covered over. The perfect fit of the stones and the hardness of the cement-facing cannot be surpassed to-day.

Bridge aqueducts are now confined for the most part to canals, which must necessarily take a level

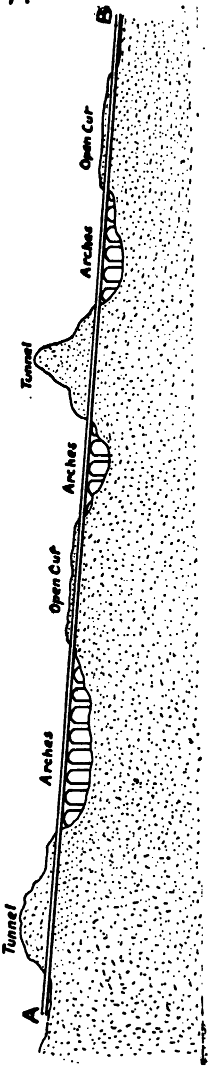


FIG. 141.—Roman aqueduct.

course between locks. The modern engineer has a great advantage over his predecessor of two thousand years ago in the large iron or steel pipes, which enable him to make use of the physical law that a fluid tends to find its own level, and will flow through a pipe of indefinite length, provided that the exit be lower than the entry, no matter how many times and how far the pipe rises and falls in the intervals, provided that it does not rise at any point above the altitude of the entry. (Under certain circumstances even this last condition need not be fulfilled if the water be siphoned.)

THE MODERN AQUEDUCT.

In Fig. 142 is shown diagrammatically the course of an aqueduct of modern type running over undulating country.

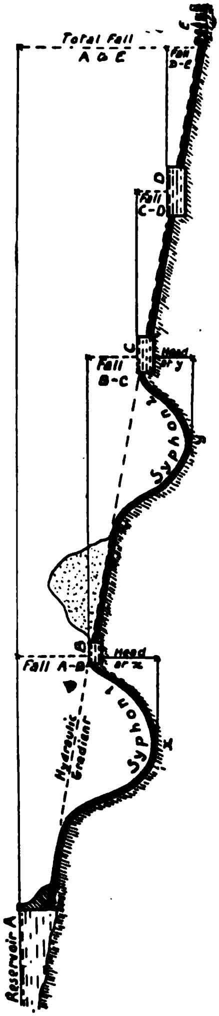


Fig. 142.—Modern aqueduct, with siphons.

The vertical heights are purposely greatly exaggerated proportionately to the length.

A dotted line, running from the reservoir A to the point of delivery E, indicates the "hydraulic gradient" or average rate of fall between the two extremities of the aqueduct. All tunnels and masonry ducts are made to follow this gradient, so that water shall not flow faster at one place than at another and the pipe portions—that is, the siphons—also follow it in that the ends of each siphon lie on the gradient. (Please observe that these siphons are only so called for convenience' sake.) A real siphon takes water over a point higher than the surface of the source, the condition necessary being that the delivery end shall be lower than the source. Siphons of the

kind shown in Fig. 142 are also named "inverted siphons" to distinguish them.

It is usual to divide an aqueduct which has a large total fall into several parts by "balancing reservoirs" B, C, D. In Fig. 142 a horizontal line has been drawn at the level of the reservoir to a point over E to show the extent of the drop between these points. If a continuous closed pipe-line were used, the pressure at E might be excessive, and in event of an accident it would be difficult to execute repairs. If, however, the length be subdivided, as shown, the greatest pressure of any one section, between A and B, B and C, C and D, D and E, is dependent on the "head" of water in that section only. In our sketch the points of greatest pressure are obviously x and y, the lowest part of siphons 1 and 2, the "heads" being respectively the difference in the level of the reservoir B and of x, and of reservoir C and of y. In the tunnel and cut-and-cover* portions (C-D, and D-E), which follow the hydraulic gradient, the water runs freely and sets up but little pressure, though the masonry may be designed to withstand considerable stress.

* By "cut and cover" is meant the method of scooping a trench in the ground and constructing in it a closed masonry duct, which is afterwards covered up with earth.

THE SIPHONS.

These parts of an aqueduct must be furnished with mechanism to minimize the effects of a burst, and to keep them clear of the silt which tends to collect at the lowest points.

We may suppose siphon 1 to be twenty miles long, and made up of pipes of large diameter. If it burst at *x*, the escape of the water in the pipes alone would be a serious matter, to say nothing of that in the reservoir.

It is obvious, therefore, that for safety's sake the engineers must provide automatic valves which shall close if the flow of water exceeds a certain prearranged velocity, as it would do in the case of a burst. In the lower leg of the siphon (that further from the source) ordinary flap valves opening only in the direction of the normal flow suffice, since the change of direction would here be sufficiently gradual to prevent any shock when a valve closed. In the upper leg, however, a valve of this kind would come into action with a suddenness that must burst the pipe. (On a domestic water supply connected with the town mains screw-down taps are compulsory, to prevent the flow being stopped too suddenly.) So the

valves are of a different type—circular discs mounted on spindles projecting through the sides of the pipe, turned automatically across the bore by external mechanism to close the pipe gradually when the water-rush releases a trigger.

For the cleaning out of siphons *scouring valves* are fitted at the lowest points.

The pipes themselves are very carefully made, and tested with water at a considerably greater pressure than they will have to withstand under ordinary conditions. Where an ordinary spigot and socket joint (Fig. 143) is used, the pipe is cast with the socket end downwards, so that the metal shall be densest at the part most liable to fracture. The joints are caulked by running molten lead in, and driving it tightly into place by hand or with special machinery, the shape of the socket giving the lead a very tight grip. Full particulars of every pipe are entered as it is laid, for future reference. Whether the pipes be placed above

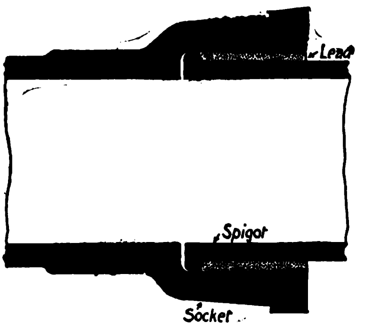


FIG. 143.—Pipe-joint staunched with lead.

ground or buried in trenches—in cold countries they are buried two feet or more deep to be beyond the reach of frost—they must be securely anchored to masonry or rock on the slopes of hills and at curves, to prevent sliding in the one case and straightening in the other. The engineer is careful to keep all curves, whether vertical or horizontal, as gentle as possible. I may mention in passing that the Thirlmere to Manchester aqueduct includes thirty siphons of various depth and length.

NOTABLE AQUEDUCTS.

We have already noticed briefly the pipe-lines connecting Manchester, Liverpool, and Birmingham with reservoirs in distant hilly collecting grounds; but no mention has been made of the largest—as regards capacity—aqueduct in existence, the New Croton. This delivers the waters stored in the Croton River Valley by the dam described in a previous chapter and its auxiliaries to New York, 33¼ miles away. A remarkable feature of this aqueduct is the large proportion—29¾ miles—"in tunnel." Where the tunnels are under pressure (about 7 miles in all) they are of circular form, 12¼ feet in diameter; where not under pressure, the section is of horseshoe shape,

13 feet 7 inches high and wide. For $2\frac{1}{3}$ miles eight rows of pipes, 4 feet in diameter, replace the tunnel, and the remaining mile is in "cut and cover." As the aqueduct approaches the Harlem River it falls on a steep gradient to the top of a vertical shaft 174 feet deep and $12\frac{1}{4}$ feet in diameter, down which it passes into a horizontal tunnel, 1,300 feet long, running under the river. At the other end of this is a second vertical shaft 321 feet high, to allow the water to rise into the tunnel that carries it to the Jerome Park Reservoir in the city of New York. This is a good example of a masonry-lined siphon.

The aqueduct is able to pass 300,000,000 gallons of water a day. It cost $20,000,000 to build, and ranks high among engineering feats. Of the tunnelling work of the scheme there is no need to speak here, as it properly belongs to a later chapter.

THE CATSKILLS AQUEDUCT.

The engineers are busy on another aqueduct which will presently bring the waters of the Ashokan Reservoir (described on pp. 260-262) to New York. The construction of this line is a colossal undertaking, for, apart from mere length—82 miles—there are great

FIG. 144.—Closing 30-inch locking-bar pipes in hydraulic press.

FIG. 145.—Testing locking-bar pipes with high-pressure water.
(Photos, Messrs. Mephan Ferguson, Ltd.)

physical difficulties to be overcome. The aqueduct has a diameter of about 17 feet, and will convey 500,000,000 gallons daily. This huge conduit will leave the reservoir in a deep trench, cross two rivers, and burrow a mile through the end of a mountain. After that it will run to the high ground on the northerly side of the Rondout Valley. Here comes a great piece of engineering, the sinking of two shafts, each 750 feet deep, and the driving of a tunnel 4½ miles long to connect their bases. Progressing along the hill-side, it dives through the Shawangunk Mountains near Lake Mohonk, follows the Wallkill Valley for 4 miles, drops down a shaft 480 feet deep, travels in a 4½-mile tunnel under a river, and rises through a second shaft. A trench carries it toward the Hudson River, which it meets at Storm King Mountain. A third siphon will be needed to take it under this river. Owing to the great pressure in the siphons it is essential that the concrete lining should have a firm backing, and the engineers are therefore obliged to go down to solid rock for the horizontal tunnel of each siphon. At Storm King the Hudson is more than half a mile wide and 90 feet deep. But the rock is far below the river bed, and it seems likely that the siphon here will have to be much more than 1,000

feet deep, and able to stand a pressure of over 500 lbs. to the square inch.

The aqueduct is destined, after crossing, to follow the left bank of the Hudson to the Croton River, under which it will burrow, and to run to a new storage reservoir 3¾ square miles in area, at Kensico, near White Plains, forming a two-months' reserve should the aqueduct have to be closed on the Ashokan side. After Kensico come the Scarsdale filter beds and the terminal distributing reservoir at Hill View, in Yonkers, just north of the city boundary.

The distribution of the water will be a big business in itself, as conduits must be carried from Hill View under the East River near Hell Gate to supply the boroughs of Queens and Brooklyn. Another tunnel will make the passage of the Narrows of New York Bay to Staten Island, where there will be a terminal reservoir 125 miles from the Ashokan Reservoir.

This gigantic scheme will occupy the engineers for several years to come, and when it is finished it will far surpass in magnitude even the New Croton Aqueduct itself.

THE COOLGARDIE PIPE LINE.

So far we have been considering only "gravity" aqueducts, through which the water flows naturally

by its own weight. The motive power in such cases costs nothing at all.

In Western Australia we find the most striking illustration of an aqueduct which has its source at a much *lower* level than the towns which it supplies and which must have the water *forced* through it by mechanical means.

When the great inland goldfield of Coolgardie was discovered in 1892 the population of that part of the country began to increase at a rate that sorely perplexed the Government. The region is almost waterless, and scarcity of water (which rose in price to £4 per thousand gallons, and very bad water at that) for all purposes caused much distress and sickness among the population that flocked in to get its share of the gold. After much money had been wasted in sinking wells, it was decided to fetch a copious supply to Kalgoorlie—23 miles beyond Coolgardie—from the mountains close to the western coast. This meant the laying down of 350 odd miles of steel pipes, 30 inches in diameter, to deliver 5,000,000 gallons of water daily to the goldfields.

A dam was thrown across the Helena River to impound a large reservoir, at a level of about 340 feet above the sea. Now, Coolgardie lies more than

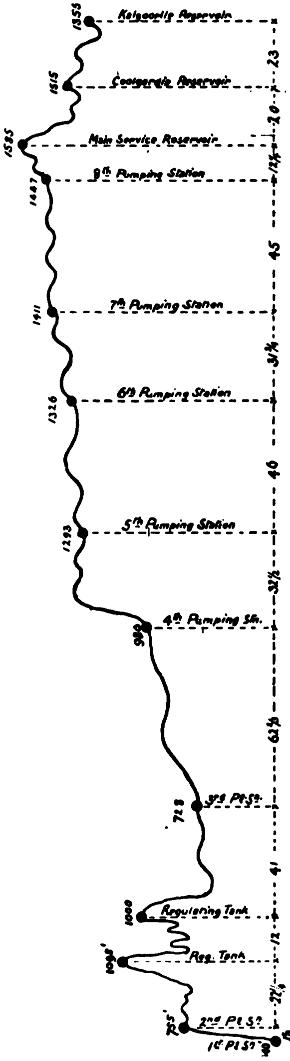


FIG. 146.—Profile of Coolgardie Pipe Line, giving heights of pumping stations.

a thousand feet high, and on the farther side of ground which is higher still. As water will not run uphill of its own accord, an elaborate system of pumping stations and receiving tanks was included in the scheme. A diagram (Fig. 146) shows the eight pumping stations, which raise the water in as many stages from Helena Reservoir to Bulla Bulling Main Service Reservoir, whence it flows by gravity to Coolgardie and Kalgoorlie. The approximate heights of the stations, of the receiving tanks which feed them, and also of two regulating tanks between stations 2 and 3, are given in the sketch, as also the mileage of the intervening distances.

THE PIPES.

After a series of careful tests, the Government adopted a novel form of pipe, invented by Mr. Mephan Fergusson, of Melbourne, and known as the locking-

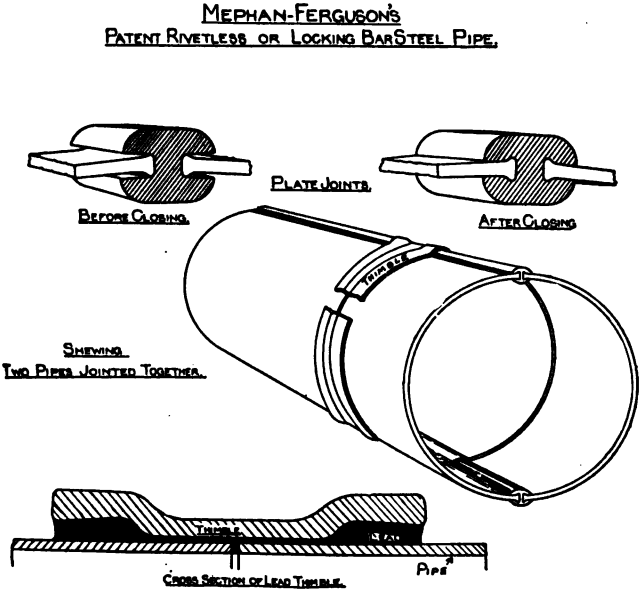


FIG. 147.—Details of locking-bar pipes.
(*By permission of Messrs. James Simpson and Co., Ltd.*)

bar pipe. A pipe consists of two plates of steel, each of the full length of the pipe and bent to a semi-circular form. The edges of the bars are beaded and inserted in long bars having a deep groove on either

side, which are closed cold on to the plates by powerful hydraulic machinery. (See Figs. 144 and 147.) Each pipe is 28 feet long and 1/4 inch thick, and weighs 1 1/2 tons. Before being passed it is subjected to an hydraulic pressure of 400 lbs. to the square inch. (Fig. 145.) Very few of the Coolgardie pipes leaked even to the extent of a few drops, so close was the joint. The finishing process was to dip the pipe into a bath of gas-tar and Trinidad asphalt, allow it to drain a minute, and revolve it quickly, so that the coating should be distributed evenly as it set. Some 60,000 pipes were required for the line. The convenience of being able to import the parts, which packed into comparatively little space, and assemble them in the country, was a strong point in favor of this particular type, and no doubt led to its being chosen.

Two factories were kept busy assembling the pipes, which were dispatched, as fast as closed, along the railway beside which the pipe line is laid throughout its course. Two trucks would accommodate between them a stack of eight pipes, loaded in eighty minutes and unloaded in an hour.

Where they cross the salt-impregnated beds of former lakes the pipes are laid on trestles and covered

over with sawdust packed between them and an exterior jacket of corrugated iron. Elsewhere they are buried in a trench, dug deep where the ground is loose (Fig. 148) or mounded over where it is hard (Fig. 149), so that they shall be protected from the heat and not require expansion joints.

The work was divided into sections of about 14 miles, each operated by a separate gang of men. When the works were in full swing seven gangs were engaged, and as the work to be done was the same

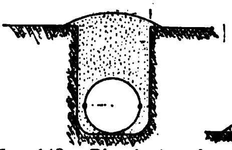


FIG. 148.—Pipe in trench.

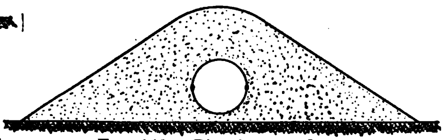


FIG. 149.—Pipe in mound.

throughout there was considerable rivalry among the parties. Careful supervision by inspectors, responsible for the quality of the work, ensured the maintenance of a high standard. "The rate of progress during the last three months, before approaching completion caused disbanding, was, per day of eight working hours of seven gangs, $1\frac{3}{8}$ miles of laying, jointing, and complete filling in of trenches. The appliances in use by each gang consisted of pipe-lowering trestles (see Fig. 150), four skids (one pipe expander, one

lead melter and retainer, and the engine and caulking plant....Foremost were the men repairing the coating in the parts damaged during unloading or transportation, or where it had become defective owing to exposure for a considerable time to the intense summer heat; and in the same set were the pipe-scrapers and locking-bar chippers, who chipped or scraped off the coating at each end of the pipe for a distance of about 6 inches, to insure good lead-running. Next came men cutting manholes in the side of the trench opposite the joints a little ahead of those laying the pipes in the trench, and following these came the ring-setters, who wedged up the joint ring to such gauge as would give a lead joint of uniform thickness. In succession were the lead-runners, whose work was, when possible, kept at least forty or fifty joints ahead of the caulking machine, especially in winter, as showery and cold weather affected the quality of the lead-running; thus stoppage in such weather, or defective work which had to be remedied, did not delay the caulking operations. Following on were the hand-caulkers, who caulked the joint at the locking-bar and for a distance of about four inches on each side of it....After the hand-caulkers came a machine, and as each joint was finished the joint inspector examined it. Pipes were

Fig. 150.—Lowering pipes into trench, Coolgardie Pipe Line.

Fig. 151.—Running lead into joints.
(Photos, Messrs. James Simpson and Co., Ltd.)

covered to a depth of at least 12 inches as soon as the inspector had passed a joint and it had been tarred, so that the partial filling-in was only two or three joints at most behind the machine. The completion of the filling-in and the formation of the covering bank was always 400 yards or more behind the machine."*

The caulking machine was constructed in two halves, to fit over and under the joints, the top half carrying an electric motor supplied with current through a cable, a quarter of a mile long, from a dynamo worked by a portable oil-engine. A number of small rollers, working backwards and forwards round the pipe along each edge of the joint, pressed the lead home, and were then replaced by knives which cut it off neatly.

THE PUMPS.

The total vertical distance through which the water has to be lifted is 1,290 feet; and the frictional resistance of the pipes is equivalent to a further lift of 1,156 feet. Add certain other factors, and we find that the pumps have to overcome, in eight stages, a

* "The Coolgardie Water Supply," by C. S. R. Palmer. "Proceedings of the Institution of Civil Engineers."

pressure equal to that of water standing in a frictionless pipe rising vertically 2,635 feet.

As 5,000,000 gallons have to be pumped daily, the machinery at the pumping station is of a very powerful and capacious kind. Twenty Worthington Pumps were installed by Messrs. James Simpson and Co., of Newark-on-Trent, England; three being assigned to each of the first four stations, and two to each of the last four. Great care was needed to avoid mistakes in packing, and to insure that every one of the twenty groups of machinery should arrive complete at its proper station. Each group was therefore given a distinctive color and letter, and every part painted with the color of the group to which it belonged. No parts of different groups were allowed to be packed in the same case. As a result of these precautions only a single ½-inch hydraulic valve was reported missing out of some 5,000 packages transported from England to various points along the pipe-line.

CHARGING THE MAIN.

In April, 1902, everything was ready for charging the main by filling the reservoirs and receiving tanks in succession. This was not so easy a matter as the reader may think. If air gets imprisoned in a siphon

it may burst out, leaving a space into which the water rushes until it is filled. The sudden check then causes a "water hammer," which puts a great strain on the pipes and may burst them. A big main is charged slowly, and the air allowed to escape through valves provided for the purpose; so you will understand why the water took eight months to reach Kalgoorlie at the end of the pipe-line. But ever since it did arrive the inhabitants of the goldfields have had a plentiful supply of good water drawn from a source as far distant in a direct line as London is from Berwick or New York from Lake Erie. The price of the water has now sunk to about two dollars per thousand gallons, less than one-twentieth of that of the condensed water on which the goldfields formerly depended.

WOODEN PIPE LINES.

Where wood is plentiful and the country so rough as to make the transport of metal pipes a very difficult matter, wooden pipe-lines have been laid down, and have proved to be economical to manufacture and cheap to maintain.

On the Pacific Slope and in other parts of the United States some very large stave pipes are used to

FIG. 152.—Three lines of 7-foot diameter wooded stave pipes.

FIG. 153.—Forty-inch pipe on curve near San Diego, California.
(Photos, The Excelsior Wooden Pipe Co.)

supply towns or mining centres and irrigation works with water. The wood most generally employed is that of the gigantic Californian redwood tree, well seasoned, and cut up into staves, having the edges planed radially to the circle of which they will form part. The staves are held together at intervals—proportioned to the pressure of the water inside—by steel bands tightened up by a nut at one end screwed against a curved shoe attached to the other end.

One of the largest stave aqueducts in existence is that supplying the city of Lynchburg, Virginia. It is 19 miles long, and the pipes are 30 inches in diameter. The construction was as follows. The wood came from California ready shaped, the staves measuring from 10 to 22 feet in length. These were assembled as quickly as possible, several gangs working simultaneously at different points, and the trench in which the pipes lay filled in. To form a pipe of this kind a circular internal mould is used, which is moved along as the work proceeds. One side of each stave has a very small tongue along its centre, which digs into the flat side of the next stave when the bands are tightened and makes an absolutely watertight joint. The ends of the staves are kept staunch by the insertion of thin steel plates in saw cuts in the ends.

The plates, being a little wider than the staves, sink into the wood of the two adjacent staves and prevent any leakage. While the bands are drawn up they are

FIG. 154.—Building a wooden pipe. Observe how the staves " break joint."

tapped with hammers to cause them to slip easily over the wood, and the pipe is "coopered," or beaten inside with mallets to make the staves lie snugly together.

Provided that they are kept filled with water, wooden pipes are practically imperishable, so far as the wood is concerned. The metal bands and shoes will not last many years unless very carefully covered with some preservative against rust.

This kind of pipe is made to withstand pressures ranging up to 90 lbs. to the square inch. For pressures above this figure metal pipes are used. Its cheapness is a great point in its favor. On the aqueduct mentioned the amount saved by employing wood pipes instead of cast iron was estimated at $350,000 (£70,000), which would enable the town after twenty years to lay a second wooden conduit of equal capacity, without spending more than iron pipes (interest on the money included) would have cost in the first instance.

Denver is another city supplied through wooden pipe aqueducts, 30 and 34 miles in length respectively. Ogden, again, is fed by a wooden conduit, in this case 72 inches in diameter.

A CLEVER PIECE OF WORK.

You have doubtless heard or read of houses and other buildings being moved bodily from one site to another without interference with the occupants or

injury to the structure. Not long ago the engineers had to perform an even more difficult feat at Philadelphia. This was to move 1,200 feet of 48-inch metal pipe 11 feet laterally and 13 feet vertically from its original position, and yet not stop the flow of the water, which was about 30,000,000 gallons a day. "Careful preparations were made for moving it into its new situation while under pressure. The centre line of the main in its original position was 1.17 feet shorter than the calculated centre line for its new position. After it was moved careful measurements showed that the actual draw of the joints had only been 0.93 foot, or 0.24 foot less than was expected. This was very evenly distributed throughout the hundred joints, and the average movement of the pipe in each joint was slightly more than 0.11 inch. In order to guard against excessive pull in the joints, each pipe was marked before being moved, on the top and on each side; but owing to the fact that some of the pipes rotated 100 degrees, it was impossible to make proper reductions of the readings.... The trench for the pipe's new position was excavated to line and gradient; excavations were then made under the pipe on about 200-foot sections, and the pipe was lowered gradually to its new gradient, being

meanwhile thoroughly braced in position to prevent lateral movement. After the pipe had been lowered to the new gradient, wooden skids, upon which iron strips were fastened, were placed beneath each length, and the pipe was then moved laterally into position with screw jacks. To facilitate moving the pipe the iron strips were kept well greased. The time occupied in moving the pipe was about one month, and except for a few hours, when a cracked pipe was discovered, the line was never taken out of service, and was under a uniform pressure of 70 lbs. per square inch. To avoid accidents and delays, rigid inspection was maintained both by night and day, and men within easy hailing distance were placed along the line to ensure the immediate closing of the valves at either end in case of accident. After the pipe had been relocated it was allowed to rest for a few days until it had assumed its final position, and all joints were then thoroughly recaulked."*

A CURIOUS EXCAVATING MACHINE.

Fig. 155 is an illustration of a very queer-looking machine known as the Buckeye traction ditcher. As its name implies, its work is to dig ditches or trenches

* "Proceedings of the Institution of Civil Engineers."

for water or drain pipes. The largest specimens can excavate a trench 4½ feet wide and 12 feet deep at a rate which beats hand labor out of the field.

The apparatus consists of a platform carried on a pair of driving wheels and a pair of steering wheels, the latter broad like those of an ordinary traction

FIG. 155.—A Buckeye traction ditcher for excavating trenches.

engine. On the platform are a boiler and steam engine to operate the driving wheels and also the great circular digger, which is suspended from a couple of steel beams projecting from the rear.

The excavating wheel has two rims set as far apart as the trench cut is wide. Between these rims are

attached a series of steel buckets, shaped somewhat like a coal-scuttle without a bottom, and each rim is also furnished with a number of curved knives. The wheel has no axle, but the rims, toothed internally, run over cogs on the beams driven by the engine, and are kept from rising off these by an X-shaped framework fitted with large rollers that press on the inside of the rims.

To start operations the wheel is set in motion and its supporting beams lowered gradually till it has eaten its way down to the full depth of the trench. Then the locomotive gear is brought into action, and the machine advances at any desired speed, scooping out the loam, clay, gravel, or even small boulders which it may encounter. As the buckets reach their highest point they empty their contents on to an endless belt, working at right angles to the direction of travel, which deposits the material in a long heap at one side of the trench. Owing to the absence of an axle the digger wheel can be sunk into the ground considerably more than half its diameter. By means of steering gear the line is kept straight or curved right and left; and where it is necessary to diminish or increase the depth on a regular gradient a sighting-bar mounted on the frame of the wheel is directed

Fig. 156.—A Buckeye ditcher at work.

on surveyor's "flag-poles" set up ahead, and kept on them by the operator, who raises or lowers the frame with a hand wheel and gear. The operator has perfect control over the depth to which the excavating wheel cuts, and he can keep the bottom of the trench within a fraction of an inch of the desired grade.

The ditcher tackles any kind of ground that a man can excavate with a pick. It will eat through hard-pan, or shale, or frozen ground, and even the macadam road gives it no trouble. Should a buried log or timber get in its track it is chewed through, and a small iron pipe is treated in like manner. As for the actual feats performed by this wonderful machine, here is an example: 3,100 feet of trench 3.4 feet deep and 22 inches wide cut through clay in twenty hours. During a contest between men and machine, it took 17 men and 3 teams ten hours to cut 900 feet of trench, while a Buckeye, operated by 3 men, cut 1,500 feet. So you have all the facts for setting yourself a little proportional sum to show how much work a Buckeye man does in an hour as compared with a man using a pick.

Chapter XVI.

CANALS AND WATERWAYS.

Canals to the front again—The advantages of canals—Two classes of canals—Boat-raising devices—The lock—Mechanical boat-lifts and inclines—Excavating operations—Dredges—Grabs—Steam shovels—Floating excavators—The bucket dredge—The suction dredge—Protecting the banks—A huge mattress—Ship canals—The Suez Canal—The Manchester Ship Canal—The Kaiser Wilhelm Canal—Some American schemes—A great Canadian project—Its significance.

"THERE be three things," wrote Lord Bacon, "which make a nation great and prosperous—a fertile soil, busy workshops, and easy conveyance for men and commodities from one place to another."

Railway systems have been extended so enormously during the last three-quarters of a century that many people are unaware of the importance of canals and natural waterways as carriers of traffic. Yet for hundreds of years canals and rivers have been, and still are, in many parts of the world the chief means of transportation. The improvement of roads in the eighteenth century robbed many canals of a large part

of their traffic, and the arrival of the railroad in the nineteenth put a number of once famous canals out of business altogether. At the present time, however, there is a revulsion in favor of our neglected waterways, and many new canals of great length and size are being made at a cost which is sufficient proof that a need for them exists. Consider this, that on an ordinary good wagon road a single horse-power will draw about 3,000 lbs. at a rate of 2 miles an hour; on a railway about 30,000 lbs. at the same rate; on water as much as 200,000 lbs. Remember also that a boat will carry a much larger "paying load" in proportion to its dead weight than can a cart or a railroad wagon. Therefore under certain conditions —namely, when a high speed is not essential, and the material to be moved is very bulky for its value —take grain and coal as examples—water transport has great advantages over rail transport.

For this reason the canal has, after a period of partial eclipse, come into prominence again, and given great opportunities to the hydraulic engineer for making artificial waterways where none such exist; for canalizing rivers not naturally fitted for navigation; for linking up navigable rivers; and, what is the grandest task of all, joining ocean to ocean by

Fig. 157.—Locks on the Tellemarken Canal to surmount waterfall.

channels deep and wide enough to carry the largest sea-going ships. "Hydraulic engineering has, next to railway engineering, been the most remarkable manifestation of applied science of modern times, and in canal construction it has attained some of its most successful results."* So no apology is needed for including in this book a chapter on canals, especially at a time when the progress of the mammoth Panama waterway is arousing world-wide interest.

The subject is so large that we must here, as in connection with other branches of engineering, confine our attention to some general principles and a few notable examples. Canals in general may be divided into two great classes—(*a*) Those which require no locks or other means of raising boats from one level to another. These are comparatively rare, the most striking instance being the great Suez Canal joining the Mediterranean and the Red Seas. (*b*) Those which do require locks or other devices.

BOAT-RAISING DEVICES.

Water finds its own level. You can't grade it like a railway. Consequently every canal that has to be carried up and down hill must be broken up into steps or

* S. R. Jeans in "Waterways and Water Transport," p. 15.

"reaches," and some means found for transferring the boat or ship from one step to another. The most common device is the *lock,* shown in vertical section and in plan in Fig. 158. It consists of a masonry chamber built at the junction of two reaches; with a pair of gates, G G, at each end. It is filled by admitting water from the upper reach through sluices in the

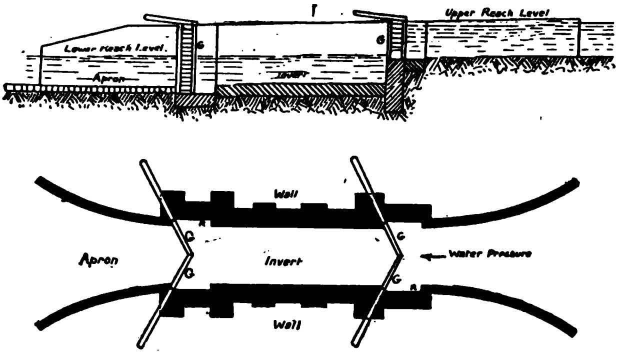


FIG. 158.—Vertical section and plan of an ordinary lock.

upper gates or in the side walls, and emptied by letting the water escape through sluices in the lower gates into the lower reach. There are usually two curved end extensions to the side walls to make entry into and exit from the lock more easy. The bottom of the chamber is a shallow inverted arch, which protects the ground below and also supports the side walls. At each end it terminates in a flat portion called the

gate floor, over which the gates move. The gates themselves are, except in the case of the smallest locks, arranged in pairs, each gate being wider than half the width of the lock, so that when closed together the two form an angle pointing up-stream. The pressure of the water against their faces is transmitted to the pivots on which they hinge, and exerts a side thrust on the walls. Some gates are not straight, as in the illustration, but curved, so as to form a horizontal arch.

In the walls are recesses, R R, in which the gates lie when open, so as not to obstruct the passage-way.

The operation of a lock is as follows. One or other pair of gates is *always* kept shut. In Fig. 158 the water inside the lock is at the level of the lower reach. On the approach of a boat travelling up-stream, the lower gates are opened, the boat admitted, the gates and lower sluices closed, and water let in from the upper reach until it raises the level inside the lock to that of the upper reach. The upper gates are then opened, and the boat floats out. If a boat were now to be passed in the opposite direction, it would be locked, and when all the gates had been shut the lock-man would release the water through the lower sluices till it sank to the level of the lower reach.

In the event of the lock-level being "against" a boat, the water is run off or let in, as the case may need, to equalize the lock-level with that of the reach in which the boat is.

The usual lift of a lock is from 3 to 12 feet, but this is far exceeded in some instances. The Panama Canal locks will have a lift of 31 feet or more.

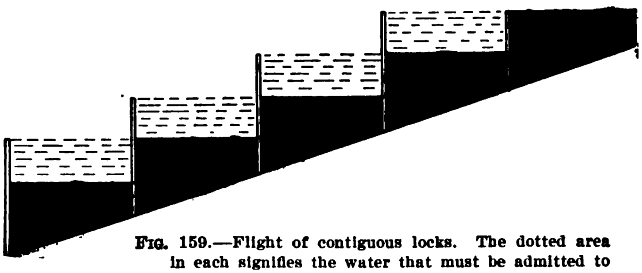


FIG. 159.—Flight of contiguous locks. The dotted area in each signifies the water that must be admitted to float a boat into the lock above.

Where the rise of the canal is very rapid, it is necessary to have a "flight" of several contiguous locks, the lower pair of gates of one lock acting as the upper pair of the lock below. In Fig. 159 we see a flight of five locks. The solid black portions indicate the water at its low level for receiving a boat from a lower lock, and the shaded portions the water that must be admitted to pass a boat up-stream. On canals where the traffic is great it is sometimes found

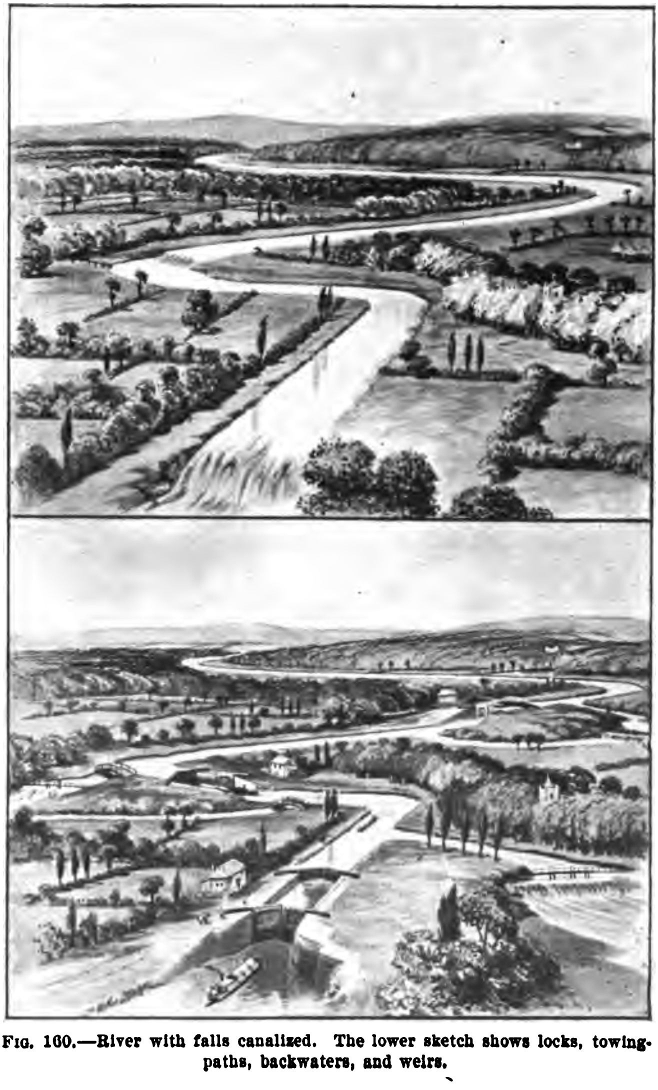


FIG. 160.—River with falls canalized. The lower sketch shows locks, towing-paths, backwaters, and weirs.

expedient to duplicate the flights, the one line being reserved for " up " and the other for " down " boats.

The size of the locks on a canal are generally just sufficient to accommodate the largest vessels that ply on the canal. At present the largest lock in existence is one on the " Soo " Canal, connecting Lakes Superior and Huron. The Poe lock, as it is named after the engineer who designed it, is 800 feet long, 100 feet wide, and 21 feet deep. The side walls, including the parts outside the locks, have a total length of 1,100 feet and a maximum thickness at the bottom of 20 feet. Five great steel gates let the water in and out. A single gate weighs 190 tons. This huge lock, built at a cost of $5,000,000, will be eclipsed by those on the Panama Canal, which, in view of the increasing size of ships, will have a width of 110 feet, a length of 1,000 feet, and a clear depth of 45 feet over the sills.

MECHANICAL BOAT-LIFTS.

A second method of raising boats from one level to another is the *lift*. In Fig. 161 we give a simple sketch of the general principle of a hydraulic lift. Two tanks are mounted on the tops of two very large

hydraulic rams having a stroke equal to the difference in level of the two reaches. The ram cylinders are connected by a pipe. When one ram is at the top of its stroke the other is fully down. If the tanks are filled equally, each exactly counterbalances the other. In the sketch two barges are about to be transferred. Tank A is not filled quite full, and conse-

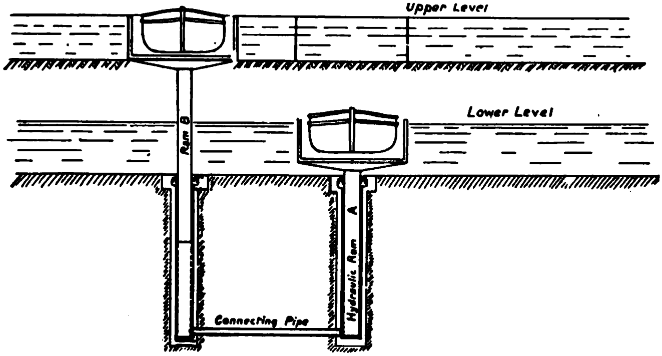


FIG. 161.—A hydraulic boat-lift.

quently ram A is unable to resist the pressure transmitted from ram B; A rises and B sinks. Both tanks are provided with lifting gates at one end, with water-tight joints, and the sides of the canal reaches have similar doors. Provision is also made for sealing the joints between the tank and canal gates when a boat is about to enter or leave a tank. At Peterborough, in Canada, there is a lift of this kind for raising 400-

ton vessels 65 feet, in place of a flight of locks. Other examples are to be found at Anderton, on the Trent and Mersey Canal, England; and at Fontinettes on the Neufosse Canal, in France; and at La Louvière in Belgium.

Another kind of lift is used on the Ems-Dortmund Canal in Germany. In this case there is but one tank, for 700-ton boats, mounted on the top of five enormous cylindrical floats, each 30 feet across and 46½ feet high. These floats move vertically about 50 feet, in wells 138 feet deep, surrounded by masonry walls a yard thick lined with iron, and have a combined buoyancy just sufficient to lift tank, water, and boat (Fig. 162).

The tank moves in vertical guides. It can be made to rise by partly emptying it, and to sink by filling it till it overcomes the buoyancy of the floats. But as this method would be attended by risks, the tank is further supported near the curves by four huge screws —spindles, 80 feet long and 11 inches in diameter, resting on solid towers of masonry. All four screws are geared together, and operated by a 150 horse-power electric motor, which is able to lift or lower the tank from one level to the other in about three minutes.

INCLINES.

Canal inclines resemble cable-operated railways in that both employ the principle of a descending load

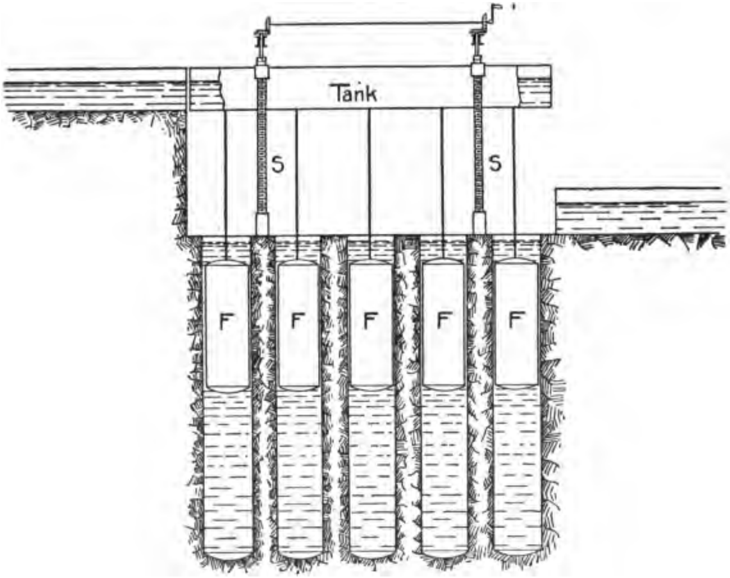


FIG. 162.—Principle of the boat-lift on the Ems-Dortmund Canal, Germany. F F are huge floats; S S are lifting screws, worked by P.

hauling up an ascending load. The Foxton Incline, in Leicestershire, on the Grand Junction Canal, may be taken as typical of the barge-carrying railway. From the lower reach to the upper extends a slope 100 yards long, on which are laid four rails for the

"up" and as many for the "down" traffic. On each set of rails runs a large tank mounted on eight wheels. The two tanks are connected by 7-inch wire ropes passing round drums in the engine-house at the top of the incline. At the foot of the slope, where the rails are submerged in the lower reach, the barge to be raised is floated into whichever tank is ready to receive it, and the end gate is closed. The engine is then started, and ten minutes later the tank attains the top of the incline, where its gates are brought into register with those of the upper reach, and the barge is floated out. This incline, designed by Messrs. G. and C. B. J. Thomas, replaces a flight of ten locks, and raises barges of 70 tons through a height of 75 feet.

The most extensive installation of inclines belongs to the Morris Canal in the United States, where there are twenty-three, with an average lift of 58 feet. The largest is 1,100 feet long, and rises 100 feet.

EXCAVATING OPERATIONS.

Whether an existing water-course has to be canalized or an artificial waterway created, the operations necessary and the machinery used are in many respects the same. The engineer first goes over the

ground very carefully with his level, determines the gradients, and decides the positions of the locks, lifts, or inclines, and what their height shall be. The fall of the ground requires deep excavating at the upper end of a reach, and embankments at the lower end. In Fig. 164 we observe the lowering of the original bed of the river just below the lock; in Fig. 163 the

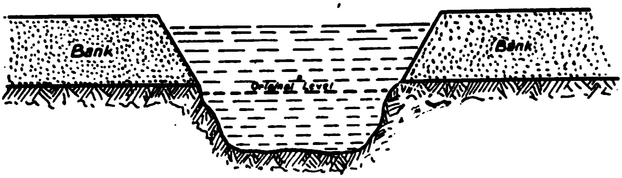


FIG. 163.—To illustrate the raising of a river's banks above a lock.

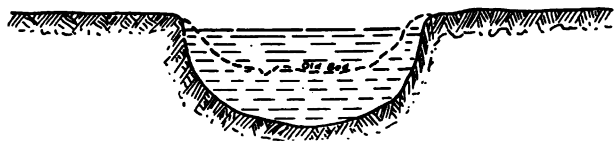


FIG. 164.—The river bed deepened below a lock.

raising of the banks above lock. When travelling on a canalized river, such as the Thames, you will notice that the banks rise so high above the water at the upper end of a reach that a view of the surrounding country is precluded; whereas at the other end you may be actually above the adjacent water-meadows.

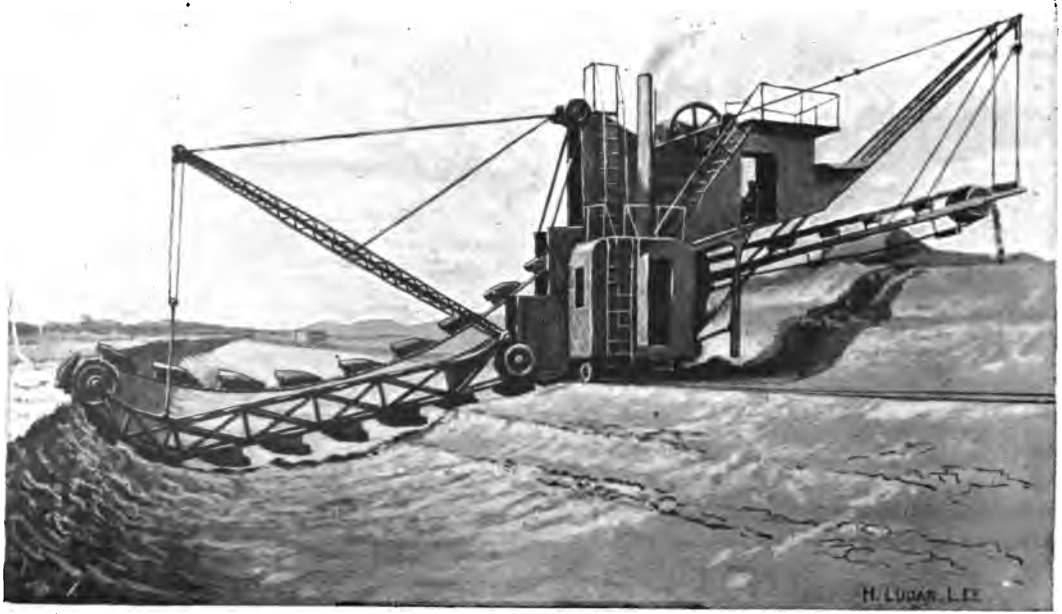


FIG. 105.—Canal bucket excavator at work.

Both excavation and embankment are done nowadays by ingenious machines of great capacity. For the removal of dry earth, clay, rock, etc., from a new cut before water is admitted, a bucket dredge of the kind illustrated in Fig. 165 is widely used. Rails are laid beside the line of the cut for a travelling machine, which supports on one side a long arm round which travels an endless chain of buckets. These buckets dig out large chunks of material, convey them into the body of the machine, and either dump them into trucks for removal, or drop them on an endless belt running over a long arm on the side away from the excavation, which deposits them a considerable distance away from the machine to form a continuous dike flanking the canal. As the excavation proceeds, the bucket chain is gradually lowered until the full depth that the dredge commands is reached. Machines of this kind will remove 100 cubic yards of soil in an hour, even when the surface is frozen hard.

Another form of digger is the *Clam-shell Grab* (Fig. 166), with two semi-circular tooth-edged jaws which open during the descent, sink into the earth, and close together when lifted. On the New Erie Canal works, near Rochester, a huge grab of this

type, which gets a "bite" of 8 cubic yards every time, has been used with great effect. The grab is dropped from a structure that resembles a Goliath crane in that it straddles its work, and runs on two parallel tracks laid on either side. The ends of the horizontal girder carried by the two towers project some distance, so that the load may be dumped clear of the excavation. The grab is most useful on long continuous stretches of similar work.

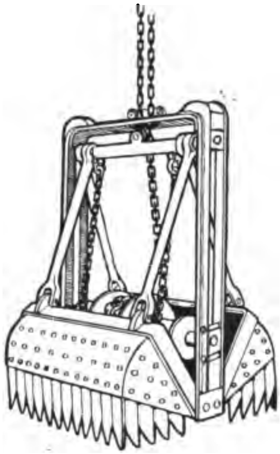


FIG. 166.—A grab for removing earth from a cut.

A third class of machine is the *Steam Shovel.* By the courtesy of the Bucyrus Co. of South Milwaukee, I am enabled to give an excellent illustration (Fig. 167) of one of their 95-ton shovels at work in the Culebra cut on the Panama Canal route, loading rock into wagons. The dipper has large teeth on its upper edge, and a flat bottom, and is mounted on the ends of a swinging arm. Be it understood that, unlike the previously-mentioned machines, the steam shovel stands *below* its work, and pushes instead of

pulling upwards. The various motions performed by the machine are, to thrust the scoop against the bank, scrape it up the face, withdraw it, and open the bottom flap so that the contents may fall into the wagon below. The largest scoops hold five cubic yards,

FIG. 167.—A steam-shovel at work on the Panama Canal.
(*Photo, The Bucyrus Co.*)

and make four strokes a minute. A single shovel can dig and load material at the rate of 6,000 yards per day of ten hours, provided that the "dirt" car trains are organized so as to keep it steadily employed. Seventy-seven Bucyrus shovels are busy on the Panama Canal, and without them it would be impossible to

do the work in a reasonable time, if at all. It has been calculated that one machine, operated by three men, can shift as much dirt in a day as 2,400 men using picks and shovels.

When the cut has been well started it is, under some conditions, filled with water to take floating excavators, which also we will review briefly. The

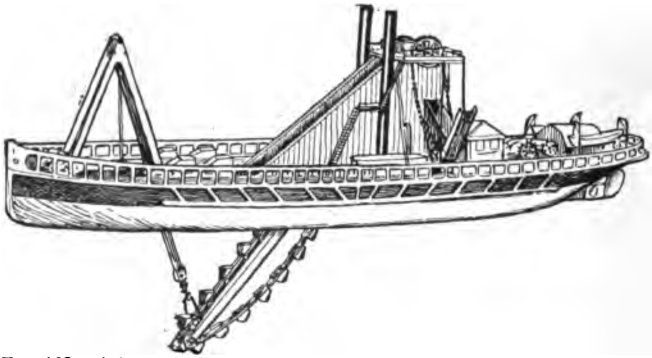


FIG. 168.—A barge dredger, showing chain of buckets, working round a movable ladder, projecting through the bottom.

bucket dredge (Fig. 168) consists of a continuous chain of buckets working round a beam which projects through the bottom or from the side of a barge, and is raised or lowered by a tackle.

Passing over the dipper and grab, respectively resembling the steam shovel and grab for dry material, we come to the *suction dredge,* which is peculiarly

adapted for working in sand and silt and gravel. The material is sucked up by a centrifugal pump through a large pipe suspended from a beam projecting from a vessel, which maintains it three or four feet above the surface of the bottom. A gigantic

FIG. 169.—The revolving knives on the nozzle of a suction dredge. (*From a photograph in "Cassier's Magazine."*)

sand-pump dredge has been constructed lately for the Mersey Docks and Harbor Board by Messrs. Cammell Lairds. It lifts 10,000 tons of sand in fifty minutes from a depth of 70 feet, and does yeoman service in keeping the Mersey channels free for the passage of the leviathans that use the Liverpool

docks. On the Erie Canal, where it traverses Oneida Lake, the dredges employed have suction pipes terminating in a series of long, flat knives, arranged in a drum (see Fig. 169) like the vanes of a revolving wind-cowl for a chimney-top. The knives are rotated sharply by shafts and bevel gearing, and bite into

Fig. 170.—A dredge depositing "spoil" on the banks of a canal by long travelling belts.

the sand or clay and mix it with water for the pipes to carry away.

Dredges of the "hopper" variety fill themselves up with spoil, and transport it out to sea to be dumped. Where there is no sea exit, the stuff is transferred to the bank by endless belts working over long horizontal arms (Fig. 170), or through pipes, either suspended

from a mast on the dredge, or supported on floating pontoons. The " long shoot " type, illustrated by Fig. 171, was used for most of the work done in the Suez Canal, the shoots being as much as 230 feet in length. Pontoon-supported pipes have flexible joints to allow of motion in the pontoons. The water with which the sand, mud, etc., is mixed, drains from the bank back into the canal.

When rock has to be treated by floating dredges, the bottom is first shattered either by blasting charges, or by heavy steel-shod breakers dropped from the dredge.

All the machines which we have noticed are marvelously powerful and effective, and lighten the work of construction to an extent which early canal-builders, whose apparatus was the wheelbarrow and shovel, could hardly have dreamed of.

PROTECTING BANKS.

The passage of a boat or ship causes a " wash " which would speedily damage a canal's banks were they not protected by stonework, concrete, fascines, or some other kind of durable surface. In Holland, where stone and timber are scarce, the wickerwork fascine is largely employed, not merely for the pro-

Fig. 171.—A long-shoot dredge. This type was used largely during the construction of the Suez Canal.
(Photo, Messrs. Lobnitz and Co., Renfrew.)

tection of embankments, but in their construction. Extraordinary fascine operations, which we may notice in passing as of peculiar interest, are carried out from time to time at the mouths of the Mississippi River, where the discharge of water is enormous, especially at the flood season, and incessantly erodes the banks. The government engineers prepare huge floating mattresses of willow poles and steel cables, load them carefully with rock, and sink them on to the river bed at points where the bank is being eaten away by the current. One of these mattresses, made to protect the banks at Memphis, measured 775 feet in length and 254 feet in width, and had an area of 4½ acres. The sinking of this vast structure was a very delicate operation, as the ballast had to be distributed all over it quickly, so that it should settle evenly.

SHIP CANALS.

The first great ship canal opened was the *Suez,* begun in 1859 and completed in 1869. The canal is notable as being the longest in existence (90 miles) and, except for the Corinth Canal, the only example of an artificial ship waterway lockless throughout its entire length. Two-thirds of its course lies through shallow lakes. The material excavated was sand,

occasionally varied by hard rock. Over 100,000,000 cubic yards of spoil was transferred by dredges from the channel to the banks. It has a surface width of 108 feet, and is 31 feet deep, and is able to pass the largest vessels in about 18 hours. Built under the management of the famous but ill-fated M. Ferdinand de Lesseps, it has entirely revolutionized sea communication between Europe and India and the east of Asia.

The *Manchester Ship Canal,* completed in 1894, was a vastly more difficult undertaking. It connects Manchester with the Mersey near Liverpool, 35½ miles away. For 13 miles from the sea entrance it follows the left bank of the Mersey, from which it is separated by earth embankments, rubble mounds, and concrete walls. One of the mounds, 1⅓ miles long, rests on two continuous parallel rows, 78 feet apart, of piles driven down into the sand with the help of a water-jet. One hundred miles of timber, 12 inches square, were used in this work. A total rise of 60 feet is effected by four locks, distributed over the last 15 miles, from Eastham, where the tidal portion ends, to Manchester.

The channel is entirely artificial, but it has been made capacious enough for 9,000-ton vessels. Over 10,000,000 tons of sandstone rock had to be removed,

and three times as much sand, clay, and shale. At Barton, where the Bridgewater Canal crosses the line, there is a very interesting swinging aqueduct, which revolves a 234-foot length of the minor canal on a central pivot to permit the passage of ships (Fig.

Fig. 172.—Swing aqueduct on the Bridgewater Canal, where it crosses the Manchester Ship Canal at Barton.

172). The Manchester Ship Canal is one of the greatest triumphs of canal engineering.

Next on the list comes the *Kaiser Wilhelm Canal,* opened in 1895, to link up the Baltic and North Seas. Its original purpose was strategic, to enable the

German fleet to pass into and out of the Baltic through German territory, but it has also proved very valuable commercially. It has a length of 61 miles and a depth of 29½ feet. The total excavation was 100,000,000 cubic yards. Where the canal traverses the peaty bed of the Kuden Lake it was necessary to form sand embankments on each side of the peat, and, when they had sunk through the peat, to dredge a waterway between them.

Among fresh-water canals those which connect the great lakes of North America with one another and the St. Lawrence, Hudson, and Mississippi rivers are the most important. A sketch map (Fig. 173) is appended to show the positions of the most notable canals existing and projected. The latter are indicated by dotted lines.

One of the shortest of canals, being but little more than a mile in length, the "Soo," is also one of the most valuable. It passes some 20,000 vessels a year, with a tonnage of 36,000,000 tons, round the Sault Sainte Marie Falls, and so gives an outlet to the trade of the country round Lake Superior, including the vast quantities of iron ore shipped from the Mesabi region. The Detroit River connects Lakes Erie and Huron, and the Welland Canal lowers vessels from

Lake Erie to Lake Ontario. The Erie Canal, 350 miles long, allows barges to travel from Buffalo on Lake Erie to Albany on the Hudson River, and so to tide water. This canal has developed enormously the

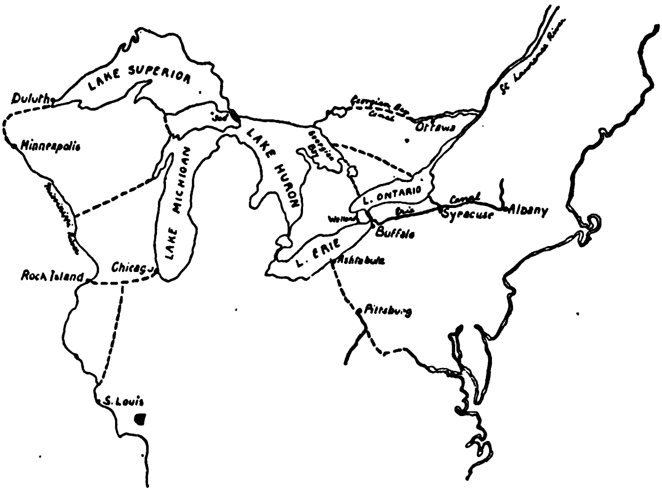


FIG. 173.—Map showing some of the chief existing and projected canals in North America.

industries of New York, and made that State the richest in the Union.

On the Canadian side of the boundary there is a scheme for spending £20,000,000 on a 430-mile waterway, which will ultimately transport vessels of large size from Lake Huron to the St. Lawrence. Starting from Georgian Bay in the lake, steamers of

8,000 tons burden will ascend the French River to Lake Nipissing, rising 56 feet through locks. From Nipissing to the chain of lakes which are the headwaters of the Mattawa, a tributary of the Ottawa River, they will pass through an artificial canal, and then drop 620 feet to tide-water in the St. Lawrence down natural channels which are to be canalized with twenty-three locks.

This canal will put the world's ports in easy communication with the Great Lakes, and shorten the distance from Chicago to Liverpool by 700 miles, or 4¼ days' sailing, as compared with the Erie Canal route; and by 3½ days as compared with the Lake Huron and Welland Canal route. It has been remarked that what the Canadian Pacific Railway was to an earlier generation, the construction of the Georgian Bay-Ottawa Canal is to the men of to-day. Both commercially and strategically the value of the new passage will be incalculable, as it will cater for the traffic of a region almost as large as Europe, while in the unfortunate event of war it would enable warships to ascend to the great Lakes. Little wonder, therefore, that the Canadians are prepared to sink a huge sum of money in the completion of a splendid waterway which Nature left not quite finished.

Chapter XVII.

THE PANAMA CANAL; IRRIGATION CANALS; A TUBE CANAL.

An intolerable obstacle to shipping—M. Ferdinand de Lesseps forms a company to pierce the Isthmus of Panama—Difficulties encountered—The French cede their rights to the United States—The present scheme—The Gatun Dam—Work in the Culebra cut—The Panama Canal the greatest of all engineering feats—Irrigation canals—A steel-lined canal at Kom Ombo—The Uncompahgre Valley project, Colorado—A long tunnel required—A projected tube canal over the Alps.

THE cutting of a canal through the Isthmus of Panama is a task that had sooner or later to be faced by civilized nations. The labor and cost of taking ships round the Horn to get from east to west of the American continent by sea could not be endured indefinitely. In 1879, M. Ferdinand de Lesseps, who by his Suez Canal had already made the rounding of the Cape of Good Hope unnecessary for eastward-bound European ships, persuaded the French to invest a huge sum in a scheme for piercing the isthmus with a sea-level canal. We need not repeat

the sad story of corruption, mismanagement, and miscalculation which, in combination with terrible physical obstacles, brought disaster to the thousands of people who had trusted the words of the aged engineer. Work on the canal was not stopped completely, but in 1905 the French company was glad to retire in favor of the United States Government, which bought it out for a sum of $40,000,000, and also purchased from Colombia for $10,000,000 a strip of territory extending five miles on each side of the route of the canal from ocean to ocean.

The main physical difficulties with which the French had contended unsuccessfully were—(1) the unhealthiness of the country; (2) the great Culebra Hill; and (3) the Chagres River, crossing the line of the canal, a stream frequently swollen by tropical rains.

The first killed workmen by the thousand; the second required a vast amount of excavation; and the third frustrated all attempts made to confine its waters. To the credit of the French be it said that before they abandoned the scheme they had excavated at all points a total of about 85,000,000 cubic yards of material.

When the Americans took the business over, the matter of deciding whether the canal should be a sea-

FIG. 174.—Sketch map showing course of the Panama Canal.

level or a locked high-level waterway was long debated. In 1906 the second alternative was adopted by Congress. The final plan, in accordance with which the engineers are now working, is shown in Fig. 174.

The canal will be 51 miles long, extending from a point opposite Colon on the Atlantic coast to a point 3 miles or so from land in Panama Bay in the Pacific. For almost 30 miles its surface level will be 87 feet above the sea. At Gatun a double flight of three locks will raise vessels to a

Fig. 175.—At work in the Culebra cut, Panama Canal. Ground removed by dredges to a depth of 152 feet.
(Photo. John Geo. Leigh, Esq.)

Fig. 176.—A cableway in the Emperador cut.
(Photo, John Geo. Leigh, Esq.)

large artificial lake created by impounding the waters of the Chagres River by a dam which will be the largest of its kind in the world—7,900 feet long at the crest, 3,100 feet thick at the base, and 370 feet wide at the top, and containing 30,000,000 tons of earth. In the face of such figures even the Ashokan Dam seems a small affair! Sluice gates in the dam will regulate the height of the water in the great inland lake and control the floods of the Chagres River.

Across the lake a channel will be dredged to Bas Obispo at the southern end, where begins the cut that attains its greatest depth in the Culebra Hill. The Culebra is the biggest problem of all. From the top of the saddle to the bottom of the canal is a perpendicular distance of about 280 feet, and the maximum width of the cut is calculated at about 600 feet. The French removed many millions of tons of stuff at this point, but the Americans must remove twice as many again. On this cut thirty of the steam shovels described on a previous page are at work eating out terraces in the sides, which are of hard basaltic rock. At Pedro Miguel the canal steps down 31 feet, and farther on, at Miraflores, there are two locks, each having a 31-foot lift, to lower or raise vessels from sea-level. All locks are duplicated.

Fig. 177.—General view of the Culebra cut.
(Photo, John Geo. Leigh, Esq.)

From the Atlantic terminal to the Gatun Dam the channel is to be 500 feet wide and 41 feet deep at mean tide. From Gatun to Culebra cutting, a distance of 25 miles, the width will nowhere be less than 300 feet, and in the cut itself, though the top width will decrease to 200 feet, the sides are to be almost vertical, to allow two of the largest vessels to pass one another easily. From the Miraflores lock to the Pacific terminal the second sea-level stretch will have a width of 500 feet.

By March 1, 1908, the Americans had excavated 28,411,879 cubic yards, more than half of this quantity being taken from the Culebra section. On that date there remained 100,000,000 cubic yards to be shifted. During October of 1907 nearly two million cubic yards were excavated from the canal prism, thanks to the energy of the directing engineers and the great capacity of the machinery employed. With so many labor-saving devices the force of workmen is kept much smaller than was originally expected; yet there are some 27,000 employés on the pay-rolls.

It is expected that the canal will be finished in 1912, at a total cost of about $275,000,000. The effects of the opening of the canal on commerce

and strategy cannot be calculated, but some results seem to be assured—that a huge amount of traffic will be diverted from the Suez route; that the trans-continental railways will be affected; that the United States, as controllers of the canal, and possessing a means of throwing their fleet from one ocean to the other in a fraction of the time now required for the doubling of the Horn, will greatly strengthen their position as a naval Power. Panama will be the great gateway between east and west, and will play an important part in shaping the future history of nations. Considering the issues involved, the magnitude of operations, and their enormous cost, the making of the Panama Canal may be written down as *the greatest engineering feat yet undertaken by man.*

IRRIGATION CANALS.

Not less important than boat and ship canals are those which distribute water in arid and semi-arid countries to make agriculture possible and profitable. In India some 45,000,000 acres have been won from the desert by irrigation canals; in the United States 10,000,000 acres; in Egypt 6,000,000 acres; and in other parts of the world probably as great an area as in these three countries combined. We have noticed

earlier in the book some of the huge dams built to impound water for irrigation purposes, and we may well spare a page or two for some of the most interesting canal enterprises designed to utilize water stored in this manner.

Irrigation canals differ from navigation canals in that they have no locks, being merely water channels, but resemble them as regards their construction, though in some cases they have special features. For instance, at Kom Ombo, 40 miles north of the Aswan Dam, a district is being reclaimed which lies 75 feet above the level of the Nile, and could not be irrigated in the ordinary manner by gravitation. The water is therefore raised by pumps into a reservoir, whence it flows through a huge semi-circular steel trough, a mile long and 15½ feet in diameter, to the plain, to be distributed by secondary canals and ditches.

The trough is built up of steel plates ¼ inch thick in seventeen 300-foot lengths. Every thirty inches the plates are stiffened by angle bars on the outside, and braced together at the top by crossbars. (See Fig. 178.) As a continuous trough would be much distorted by contraction and expansion under a tropical sun, each section rests at the ends on masonry supports shaped to fit it exactly, and containing

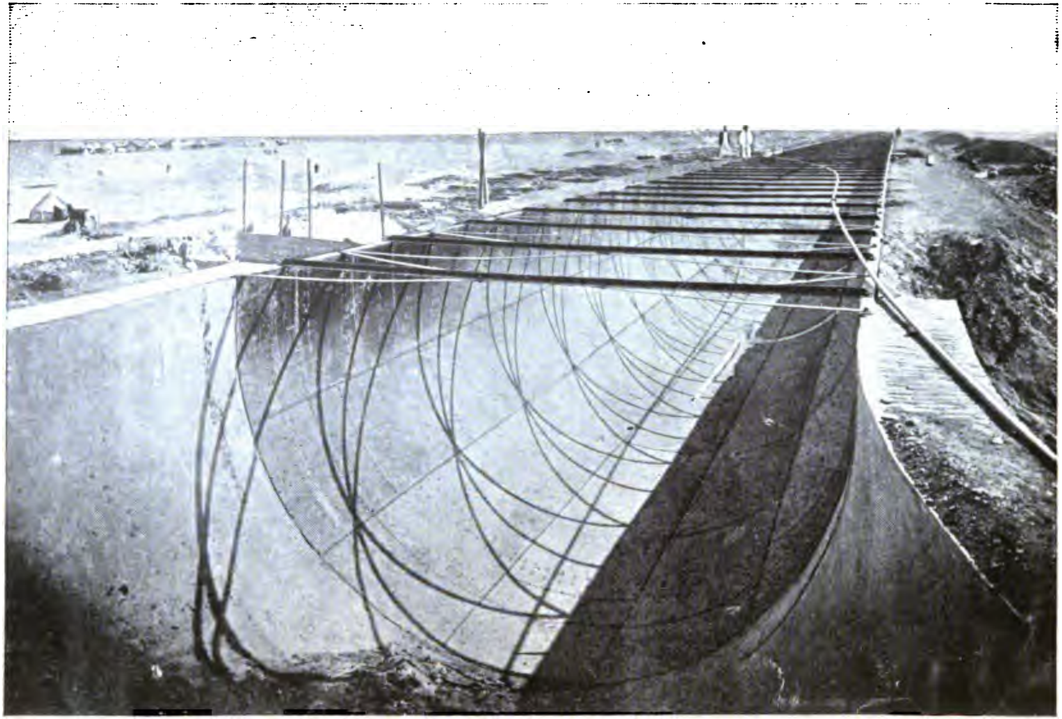


FIG. 178.—Kom Ombo Canal, Egypt. It has a semicircular steel lining a mile long and 15½ feet in diameter.
(*Photo, "Scientific American."*)

grooves filled with tarred and tallowed rope, to make a watertight packing over which the section may slide a little. The ends of two sections are 6½ feet apart. In the foreground of Fig. 179 we see a masonry support partly built and one of the overhead gantries, used for handling the plates.

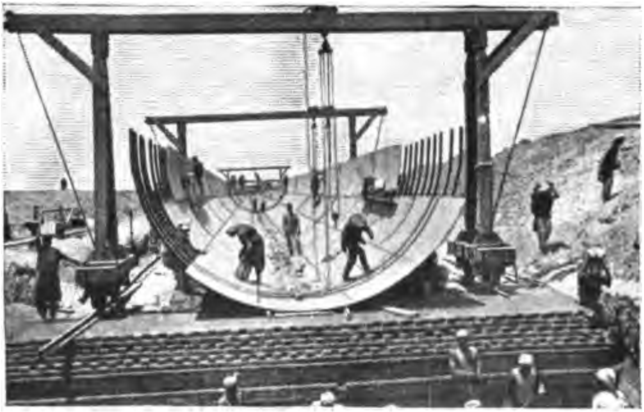


FIG. 179.—Kom Ombo Canal. Riveting the plates. The sides have not yet been banked up with sand. In the foreground is one of the masonry supports on which the sections rest.
(*Photo, "The Scientific American."*)

During the riveting of the plates each section was supported by timber cradles set 30 feet apart. When completed, its level was carefully adjusted with screw-jacks and sand, tightly rammed, was banked up on either side to take its weight and protect it externally; then the jacks were withdrawn. The inside received

FIG. 180.—The Uncompahgre Valley, Colorado. This desert will be irrigated by the canal seen on the left.
(*Photo, "The World's Work."*)

a coat of bituminous paint, applied by night. The main difficulties encountered by the engineers were the strong desert winds, which scoured the sand from under the trough, and the quarrelsomeness of the native workmen, some 7,000 in number, who were apparently more handy with their knives than with the pneumatic riveting machines, and averse to night work.

The canal passes twelve cubic metres of water a second, and already has been instrumental in converting 12,000 acres of arid waste into thriving cotton and sugar plantations, interspersed by prosperous villages.

THE UNCOMPAHGRE VALLEY PROJECT, COLORADO.

The Gunnison River, a tributary of the Colorado, flows at the bottom of a cañon nearly 2,000 feet deep, with almost vertical sides. Some miles away, and at a much lower level, lies the valley of the Uncompahgre, a sage-brush desert (Fig. 180). Between the two rises a mountain range. In order to carry the Gunnison's water to the desert, a tunnel 5½ miles long has been driven through the solid rock, sandstone, shale, and lime in the face of great difficulties. From the south portal runs a canal 12 miles in length,

which carries 1,300 feet of water per second to the point of distribution. Owing to the nature of the soil the sides of the canal are concreted throughout (Fig. 181). This canal will bring 200 square miles of desert under cultivation.

In Idaho, California, Arizona, Nevada, Wyoming, Montana, and New Mexico schemes of equal importance to the Uncompahgre are in operation; but they are all surpassed by the diversion of the Bow River, in Alberta, Canada, into a canal 120 feet wide at the waterline, 60 feet wide at the bottom, and 10 feet deep, which will irrigate an area of about 4,500 square miles.

A TUBE CANAL.

A well-known Italian engineer, Pietro Caminada, has brought forward a project for a canal to join Genoa in the Mediterranean with the North Sea, across the Apennines and Alps. For a large portion of its length the canal will consist of waterways already open, but in the mountainous regions, where the rise and fall of the course is sudden, he proposes to make use of gigantic slanting tubes in place of the ordinary open channels.

FIG. 181.—Cementing the sides of the Uncompahgre Canal.

FIG. 182.—The Cedar Creek Portal cut of the Gunnison Tunnel, Uncompahgre Valley project.
(Photos, "The World's Work.")

If you put a cork in the bottom of a tube, and stand the tube upright and fill it with water, you illustrate the principle of the canal lock which has been described on a previous page. The cork is lifted but not advanced.

Now empty the tube, slant it, and fill it again. Not so much water is required this time to bring the cork to the upper end. The cork has not, indeed,

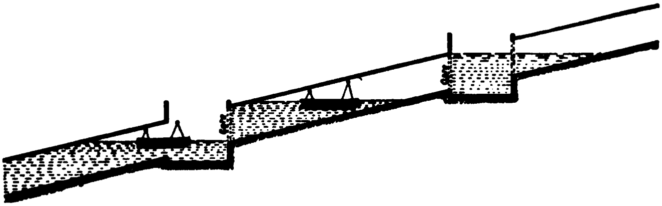


Fig. 183.—Diagram to show principle of Caminada's proposed Tube Canal across the Alps from Germany to Italy.

risen vertically as far as in the first case, but it has been *moved forward* a considerable distance.

Imagine, now, in place of the cork, barges of 600 tons burden, and the tube to be expanded to a diameter of about 50 feet, and you have a fair idea of Caminada's system. The tubes will not be continuous, but interrupted at certain intervals by chambers closed at each end by doors. This will make it possible to raise or lower a number of barges simultaneously in different sections of the line. To promote

speed the line will be doubled, one "track" for ascending and the other for descending.

Fig. 183 is a sketch to show how the system works. In the lowest section a barge has risen to the chamber at the top, which it is entering through the opened gate. In the middle section another barge is rising, and the uppermost section is being emptied to receive it. The water let out from one line of tubes serves to fill the sections in the other line.

Guides projecting upwards from the barges to engage with bars on the roof of the tubes will help to direct the craft. A model of the system on a scale of one-tenth has been constructed, and found to work so perfectly that much attention has been drawn to the project, which is calculated to transport fifteen million tons from the Mediterranean to the North Sea in a single year, at a speed which would compare favorably with that of the freight trains that are the carriers at present.

Chapter XVIII.

HARBOR WORKS.

Artificial harbors—Force of waves—Types of breakwaters—Methods of construction—Building-out—Titan cranes—Gantry method—The Dover harbor works—How the work was done—Block-making—Building the gantries—Preparing the ground—Diving bells—The island breakwater—The Admiralty Pier extension—Aprons—Prince of Wales Pier.

PRACTICALLY every country that has a sea-board has been provided by nature with one or more harbors in which a fleet may ride safely, unvexed by storms that rage outside. Political reasons, on the other hand, have compelled maritime powers to supplement the natural protection of their harbors with artificial works designed to prevent the entrance of hostile ships should war arise, and also to create entirely artificial roadsteads at points on the coast where the waves have had free play.

The force of a big ocean roller is enormous. Experiments made on the coast of Dunbar, Scotland, have recorded a maximum blow due to the water equal

to $3\frac{1}{2}$ tons to the square foot, $31\frac{1}{2}$ tons to the square yard. The design of a mole or breakwater differs widely from that of a dam, subjected to a steady calculable pressure. The roughest buffets fall upon that part of the mole immediately above and below the normal water line, so that the masonry must be solid and thick to the top, and able by its very weight to withstand the utmost force of the waves.

Difficult indeed is the task of the engineer who has to raise great stone piles in despite of the elements, and vast are the quantities of material needed for his work. It is not exceeding the truth to say that in its struggles with the sea modern engineering is seen at its best.

TYPES OF BREAKWATERS.

The form that a breakwater takes depends largely on local conditions and facilities. Sometimes it is merely a long, wide pile of stones or concrete blocks tipped at random from barges until they rise above high-water level; or again it may be a stone pile capped with solid blocks laid in order; or a wall built of blocks from the sea bottom.

Algiers breakwater illustrates the first type. For good examples of the second we turn to Portland

Harbor, where nearly 4 square miles of sea are all but encompassed by the shore and $3\frac{1}{4}$ miles of mole. (A section of the work is given in Fig. 184.) At Gibraltar 410 acres are sheltered by blocks laid on

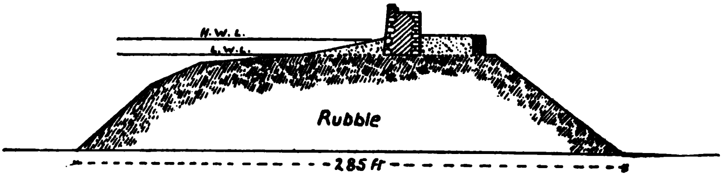


FIG. 184.—Section of Portland Breakwater.

rubble mounds. An excellent illustration of the wall type is found in the new Admiralty Harbor extension works at Dover, on which we shall concentrate our attention in the present chapter.

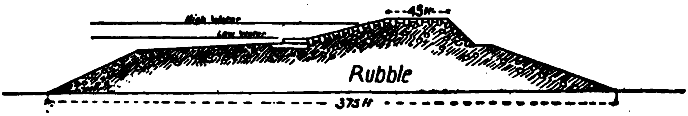


FIG. 185.—Section of Plymouth Breakwater.

METHODS OF CONSTRUCTION.

A simple rubble mound is formed by dropping the materials from hopper barges on to the desired spot. For block walls two methods are employed, the services of giant cranes being required for both.

The "building out" method. To illustrate this we may turn back for a moment to the new harbor

at Gibraltar. One of the moles is detached, or unconnected with the shore. A huge steel caisson, 33 feet wide, 101 feet long at the bottom (tapering to 76 feet at the top), and 48½ feet high, was constructed in England, towed to Gibraltar, and sunk in position on the top of a rubble mound. Thousands of tons of concrete were poured into this mould, till a single solid mass was formed, and on this the engineers raised a "Titan" crane, which may be briefly described as a large girder pivoted on a revolving turntable supported by a lofty bridge-shaped truck. Fig. 186 illustrates a crane of this kind. The longer arm, having an "overhang" from the centre of the turntable of anything up to 100 feet, does the lifting; the shorter arm carries the engine and gear for hoisting and moving the crane on its rails, and a counterweight which is shifted to balance the load. After the Gibraltar Titan had been erected, it proceeded to lay blocks in steps against one end of the caisson until it had made a fresh footing for itself, and then moved on to the new work to afford room for a second Titan. The two travelled away from each other until the mole was completed.

Under certain conditions this method is very advantageous, as the mole automatically advances

itself, and the cranes run on a solid foundation, along which they can be withdrawn in stormy weather. It has one disadvantage, however—that where the foundations for the blocks must be excavated and levelled, construction is delayed, as the cranes can do but one thing at a time. Consequently

FIG. 186.—A Titan crane laying an Apron Block.

where circumstances prove favorable recourse is had to the second, or

Gantry method. Rows of piles are driven on either side of the line to be occupied by the blocks, to support platforms or gantries for "Goliath" cranes—movable bridges fitted with winding and

propelling mechanism, situated directly over their work. The construction of the gantries is very expensive, but its cost is often more than saved by the ease afforded of distributing the necessary operations among a number of Goliaths, all employed at one and the same time.

THE DOVER HARBOR WORKS.

In 1895 Dover, the English port of the chief cross-Channel route, boasted only a single pier, built for the Admiralty in the years 1863-71.

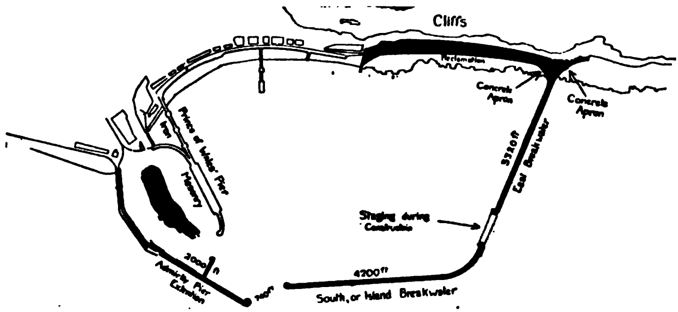


FIG. 187.—Plan of the New Admiralty Harbor, Dover. The works marked in solid black have been carried out by Messrs. S. Pearson and Son.

It is 2,100 feet long. In that year it was decided to create a National Harbor by extending the pier 2,000 feet, building an island breakwater east and west 4,200 feet long, and protecting the

eastern side with a shore arm of 3,320 feet. As an adjunct to the sea works an area of 22 acres of shore was reclaimed under the cliffs adjacent to the east arm. The works then proposed, and since carried out by Messrs. S. Pearson and Sons of Westminster, are shown solid black in the plan, Fig. 187.

A section of one of the three breakwaters is given in Fig. 188. The depth of the water at Dover varies from 61 feet to 42 feet, according to the state of the tide. The breakwaters taper slightly towards the top, which in the case of the Admiralty Pier extension and east arm is crowned on the seaward side by high parapets to protect passengers. On a level with the bottom of the parapet is a "bull-nose," or large blunt lip, bending out towards the sea, so as to deflect the water and hinder it from washing over. The greatest width of breakwater at the foundations is about 57 feet, the greatest height 90 feet. As one walks on the breakwaters it is hard to realize that the wide

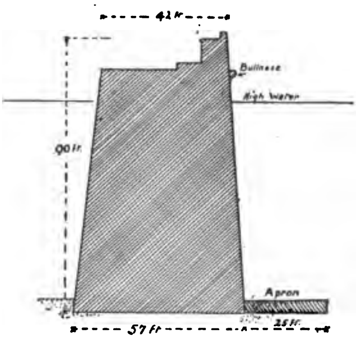


FIG. 188.—Section of breakwater, Dover Harbor.

platform is merely the top of a wall, and that the wall itself is as high as a five-storied house. Their great length makes the structures, or rather that part of them which rises above water, seem almost insignificant in the distance. It is only when you come to close quarters with the moles, and see what they are built of, and how they are built, that you understand properly the titanic nature of the undertaking.

HOW THE WORK WAS DONE.

The contractors began operations on the Admiralty Pier extension, and on cutting back into the chalk cliffs along the easterly half of the strip of shore included in the harbor. Hundreds of men, roped together, attacked the cliff face, drilling holes and blasting down great masses of the dazzlingly white substance to form a solid platform well above the sea. As the shore was at this time exposed to the full violence of the waves, great quantities of the chalk were carried away until a retaining wall of 3-ton concrete blocks had been erected on the sea edge of the reclamations by cranes running along platforms on piles driven on the cliff side of the wall. As the wall progressed the space behind it was filled in, and eventually the contractors secured an area 3,850

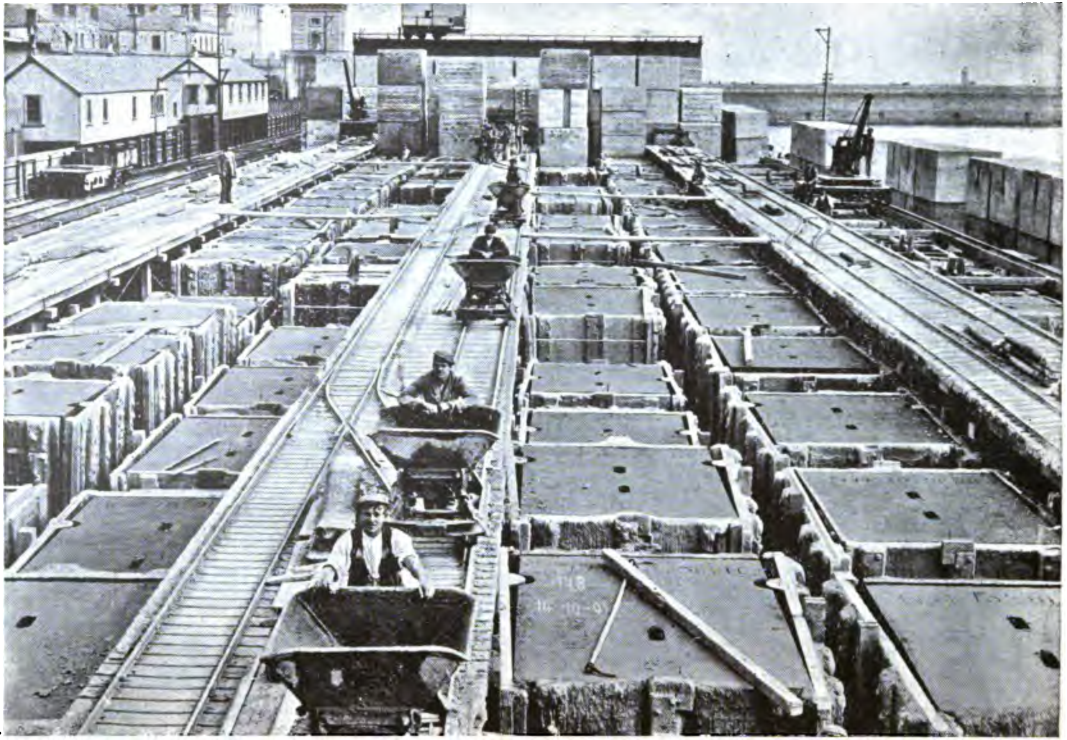


FIG. 189.—A blockmaking yard, Dover Harbor Works. Some of the concrete blocks weigh over 40 tons each.

feet long and 250 feet wide as a site for blockmaking yards, work shops, repair shops, foundries, and stores of all kinds. A strong wooden barricade, 8 or 9 feet high, was raised to protect the yards from the surf of the waves driven in by south-westerly gales.

BLOCKMAKING.

As the breakwaters are almost entirely constructed of blocks, we will glance at the process of manufacturing these great rectangular masses of concrete. There were two main block yards, one at the west end of the harbor for the Admiralty Pier extension, the other on the reclaimed ground for the East and Island breakwaters.

A picture of a yard in operation is given in Fig. 189. The blocks vary in weight from 3 to 42½ tons, the largest measuring 14 by 7½ by 6 feet. Gravel, sand, and cement, mixed in certain proportions, form the concrete from which they are shaped in wooden moulds, open at the top and having two sides removable so that the block may be extracted easily.

The sand and gravel was fetched from points on the Kentish coast by rail to the top of the cliff, shot into great hoppers, and conveyed down the face on a cable-operated inclined plane, with four tracks, the

descending laden cars hauling up empty cars. From the plane the cars pass on to a charging platform, where they are tipped into other hoppers, which automatically deliver the materials into big mixers running underneath on six sets of rails commanding an equal number of rows of block-moulds. Immediately after receiving its charge of six parts of gravel and sand to one of cement, and a due amount of water, the mixer begins to travel towards its mould, churning up the contents as it moves along the rails, so that no time shall be lost. Arriving at the mould—which has been previously well greased, for the same reason that a cook greases her cake tins—the mixer empties its load, and then returns to the charging platform. As every charge is tipped, the concrete is well rammed into the mould, and when the mould is full the surface is struck off with a straight-edge. A week is allowed for the material to set. Then along comes the Goliath crane spanning the moulds, lifts the block out of its mould, which has been loosened for the purpose, and stacks it at one end of the yard. You will see a pile of stacked blocks in Fig. 189.

After another month or so it has hardened sufficiently to be fit for use.

For the easy handling of the blocks, two oblong

holes, inclined towards one another, are moulded in the concrete by inserting wooden bolt-cores, removed when the concrete has set. Into each hole is inserted a bar called a lewis-bolt, furnished with a T-head at the lower end, which is given a quarter-turn to grip the block underneath, where there is a recess somewhat deeper than the head. The shackles on the upper ends of the bolts are then passed over the double crane hook of the Goliath.

Fig. 190 shows a block suspended by its bolts.

About 64,000 blocks, averaging 30 tons in weight, were used in the breakwaters—1,920,000 tons in all. Add the blocks for the retaining wall of the reclamation, and the apron blocks laid on the seaward side of the breakwaters, and we get a grand total of about 3,000,000 tons of masonry.

Before closing this section I should mention that all outside blocks have their sea-face covered by granite ashlar work, built up inside the moulds before introducing the concrete. A glance at Fig. 192 gives us a good idea of the facing and the method by which it is bonded with the concrete, "stringers," or longitudinal blocks of granite, alternating with "headers," which show their ends and project back into the body of the block.

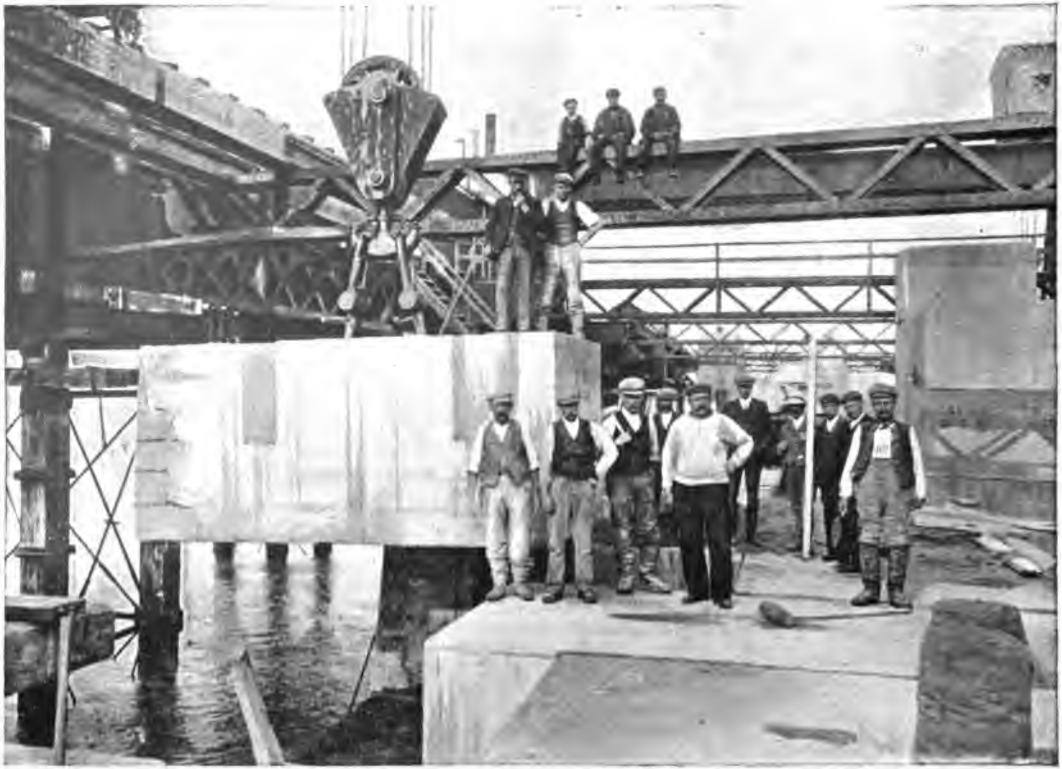


Fig. 190.—Laying the last block, Dover Harbor Works.

BUILDING THE GANTRIES.

Before any work could be done on the breakwaters, the contractors had to erect the shore end of the gantries, to accommodate the Goliath cranes. As the latter weigh 100 tons each, without load, which may add another 50 tons, these platforms required very substantial support.

First were driven in with a 2-ton "monkey" great iron-shod wooden piles, 100 feet long and from 18 to 20 inches square, in groups of six, three on each side of the line of the future block-work. Fifty feet separated each group from that next ahead, and there was a clear 70 feet laterally between the two sub-groups. Oregon pine piles were used, until, on account of the damage done to them by sea-worms, and of their lightness—which made them float when detached, to the danger of shipping—it was decided to replace them with sticks of Tasmanian blue gum, which is immune from the sea-worm, and naturally sinks. Half a million cubic feet of this wood were selected and ordered by the contractors' expert, who made a special journey to Tasmania for the purpose. We may mention in passing that the harbor works

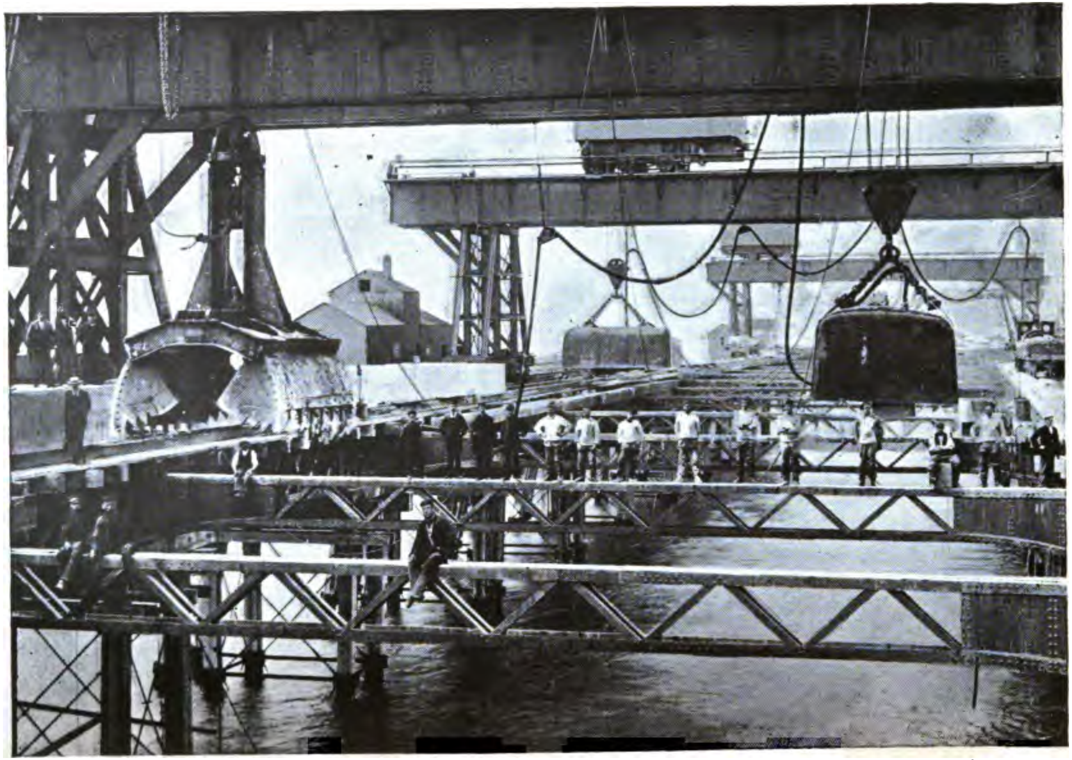


FIG. 191.—Divers and diving-bells, Dover Harbor Works. On the left is seen a grab. Observe the three Goliath cranes.

consumed one and a half million cubic feet of timber in all.

On the top of the piles were placed short cross girders, to carry the three main longitudinal lattice-work girders connecting the groups in each gantry. The gantries were braced diagonally by strong ties, and laterally by lattice girders—the men are seen standing on them in Fig. 191—and covered with a heavy timber flooring to form a base for the two Goliath tracks, 100 feet apart, and for the railroad tracks over which the blocks were brought from the yards on the frames of discarded six-wheeled engine tenders. Ordinary four-wheeled trucks were too light for the work.

PREPARING THE GROUND.

As soon as a considerable length of staging had been erected by the pile-drivers working on the outward end, a Goliath was established to operate the great clam-shell grab (see Fig. 191, on left), which, if it got a good bite, would bring up 5 tons of stuff. When the ground proved too hard for it, a "breaker"—a solid block of iron with three projecting teeth—was used to pound the sea-bed into pieces which the grab could gather.

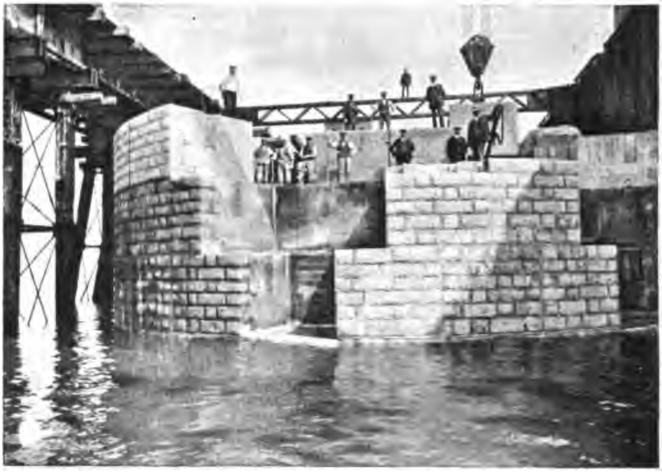


Fig. 192.—The west end of the Island Breakwater, Dover Harbor Works, showing granite masonry facing of blocks.

Fig. 193.—Inside a diving-bell.

Behind Goliath No. 1 came that for working the diving bells—steel boxes 17 feet long, 11½ feet wide, and 6½ feet high (the largest), provided with seats and a wide tray to contain the material excavated. Four men could work comfortably inside the largest 40-ton bells.

The bell moved in stages from side to side across the end of the wall, against which one side rested to keep it in the true line. The bells were lighted electrically, and furnished with telephones connecting with the crane platform. When a full breadth had been excavated and levelled, the Goliath moved on and made way for a third and fourth engaged on laying the blocks, the under-water courses of which required the services of divers. In Fig. 196 we see the boats attending two groups of divers, and, looking more closely, the crane ropes suspending a submerged block. Each diver informed the craneman above by signals when the block was in its exact position, and when to lower it on to its bed. He then gave the lewis bolts the necessary twist to disengage them, and they were hauled up.

The blocks are "keyed" together by bags of cement lowered into semicircular grooves moulded in the faces so as to come opposite one another in pairs

(Fig. 195), and further secured by iron bars where they form the ends of the breakwaters.

Rapidity of work was necessarily dependent on the weather. In rough seas nothing could be done; when the water was calm, operations continued night and day. The proper balancing of the different stages of

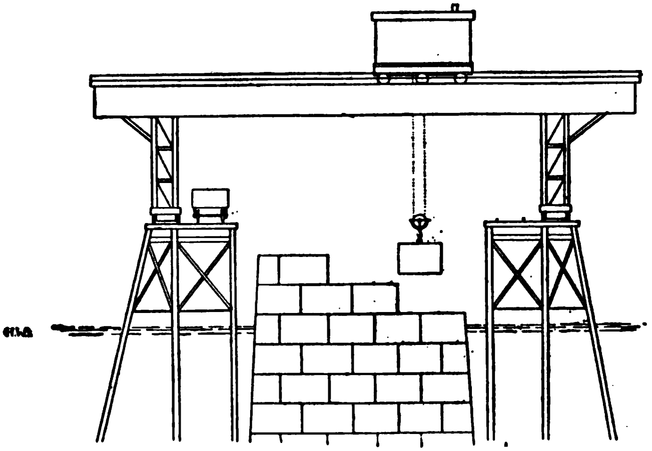


FIG. 194.—Diagram showing piles supporting platform for block-laying Goliath crane.

preparation and construction, so that no one stage should get too far ahead or impede that behind, was the contractor's first care; and things went forward at, on the whole, a very satisfactory rate.

It is a testimony to the growth of engineering science that, whereas the old Admiralty Pier was

advanced only 91 feet per year, the recently-built extension, of equal section, has been put together at a yearly rate of 600 feet. In one particular month 75 feet (= 601 blocks) were laid. We must remember that, owing to the strong currents and the depth of the water, block-laying was possible for but three hours on each tide, and on rough days not at all.

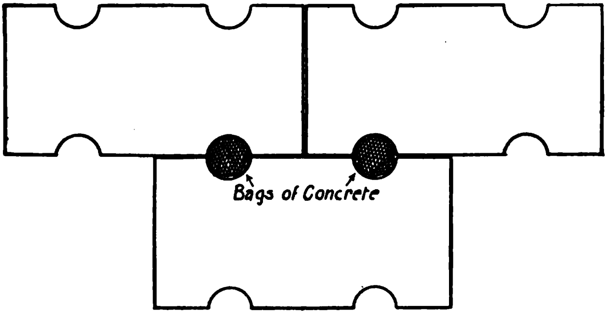


Fig. 195.—Diagram showing how blocks are keyed together.

THE ISLAND BREAKWATER.

To save time the contractors decided to build the island breakwater independently of any fixed connection with the shore. As a starting-point a great steel frame was set up in the sea at the east end of the site. Unfortunately, before it was sufficiently complete to be impregnable a great storm rose and entirely destroyed it, causing a delay of six months

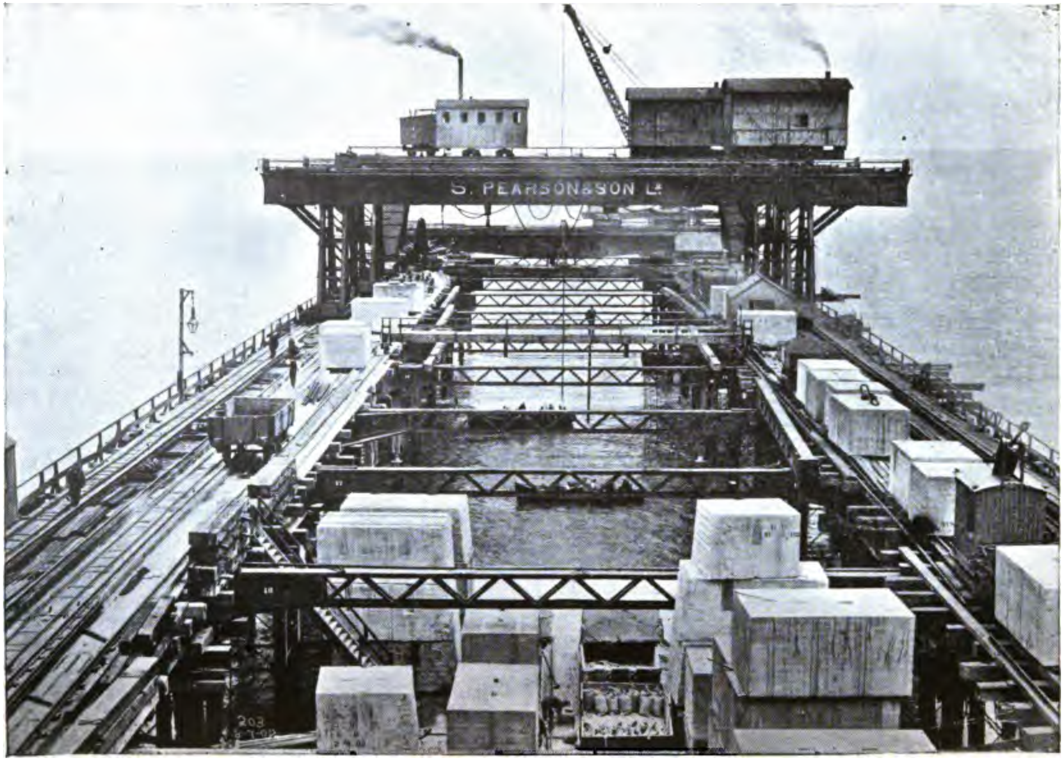


Fig. 196.—Divers at work, Dover Harbor Works.

for the removal of the débris. Eventually the gantries of the east arm were carried across the south-east mouth of the harbor and continued to the west end of the island breakwater.

THE ADMIRALTY PIER EXTENSION.

This part of the scheme was completed first, but only slightly ahead of the much longer east arm, though it had a year's start. Being exposed to the full violence of the south-westerly gales, the work was much more hindered than that on the eastern breakwater, which it partly protected; hence the difference in the rate of progress. An interesting feature to be noted in connection with the extension is the building of a temporary lighthouse on the frame of a Goliath, which was moved forwards with the cranes so that pilots might not drive vessels on to the new part of the arm.

THE APRONS.

Along the seaward side of all the breakwaters, and projecting 25 feet horizontally from the foot, is a solid "apron" of 13-ton blocks, 3½ feet thick, sunk more than half-way into the sea-bed. It was laid by powerful jib-cranes to protect the foundations from

FIG. 197.—A Tasmanian blue-gum forest. The shaped logs are 100-foot, 10-ton piles for the Dover Harbor "Goliath" gantries.

the undermining action of the waves. At the angles which the east arm makes with the shore are two large semicircular aprons shelving upwards with a gentle slope. These give the incoming waves a circular motion which plays one off against another and robs them of their force.

THE PRINCE OF WALES PIER.

This is not part of the Admiralty works, and I refer to it only because its construction illustrates a second kind of pile-driving. For 1,200 feet it is an iron structure supported by hollow cast-iron piles, 8 inches in diameter internally, driven in groups of three, except at the three "stiffening bays," where the number is increased to five. In all cases the two outside piles were *screwed* into the chalk at a slight angle to the vertical—"straddled." The lower ends of these piles had sharp points, and carried steel blades arranged in a spiral fashion so as to form a gigantic screw. As "screwdriver" was employed a pair of hydraulic rams, terminating in racks, which engaged with a toothed wheel attached to the top of the pile. Every stroke of the rams gave the pile a quarter-turn.

For the centre piles, which have to bear the weight of a railroad track, a different method of sinking was employed—to wit, the pneumatic-caisson method, noticed in the chapter on Bridge Foundations.

Cylinders, nearly 9 feet in diameter, were sunk in the chalk, the men working under pressure. The portion below the sea-bed was next filled with concrete, capped with a large foundation stone, to which

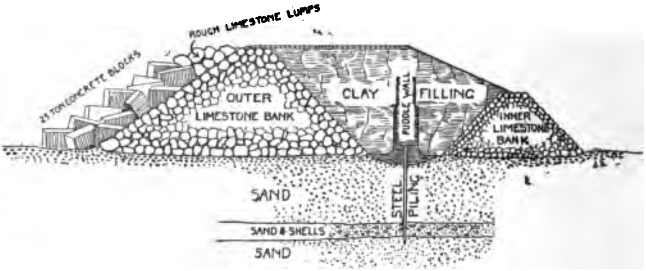


FIG. 198.—Section of breakwater to protect the Hodbarrow Iron Mines, Cumberland.

the central pier was bolted. More concrete then filled the cylinder up to bed level, and the upper sections of the cylinder, used for sinking only, were removed for use with other piers.

The National Harbor was begun in 1898 and finished in 1908. Ten winters of the fiercest storms availed nothing to injure the permanent work. At times the great rollers fling themselves furiously on

the walls, and anon hurl "green" water over the parapets, but not a block is started; they have a better chance of leaving a mark on the white cliffs of Dover. It has been a straight fight between man and Nature, and man has won so far. Great Britain has gained one more refuge for her shipping—one more boom-protected roadstead for her floating forts should her naval strength be challenged.

[*Note.*—The photographic views illustrating this chapter were kindly supplied by Messrs. S. Pearson and Son, Ltd.]

Chapter XIX.

TUNNELS AND TUNNELLING.

Tunnelling difficult and risky work—Roman tunnels—Explosives and the powder drill—The shield principle—Classes of tunnelling—Mountain tunnels—Surveying—Transferring the centre line down a shaft—Operations underground—Methods of excavating—The Simplon Tunnel—The Brandt rock drill—Ventilation—Difficulties encountered and overcome—The headings meet —Accuracy of calculations—Other famous mountain tunnels—The Mont Cenis—The St. Gothard—The Arlberg—The cut-and-cover system—The longitudinal trench method—The transverse trench method.

A TUNNEL, being but a darksome hole made through the earth, cannot compare, as regards spectacular effect, with the big bridge or dam. Yet the driving of tunnels is a branch of engineering which derives particular interest from the fact that it continually places the engineer in difficulties surmountable only by the exercise of great ingenuity, yet in few cases unsurmounted. The builder of a bridge works out his calculations and assumes with confidence that if certain conditions be fulfilled his bridge will in time be an accomplished fact. But what man can

foresee the unpleasant surprises which may await him as he burrows through a mountain or under a river bed? The work *may* prove quite straightforward from start to finish. On the other hand, it is at least equally probable that his patience and resource will be taxed to the utmost before his task is complete. His great foe is water, whether as the subterranean stream suddenly tapped by the blast, or mingled with sand and clay to form a treacherous stratum. Against the crushing of his timbering and masonry he must always be on guard. Add the discomforts and inconvenience of working in a very confined space to which there is access only through the passage-way already cut, where proper ventilation is obtained with difficulty, and where the heat is often well-nigh intolerable. On the point of hardship, tunnel-driving, in common with mining and other underground work, is far ahead, or behind, as you please, most other branches of engineering.

The Romans have left us some very fine examples of tunnel driving, the most notable being that made to drain Lake Fucino. It is 3½ miles long, and has a section of 6 by 10 feet, and is said to have occupied 30,000 men for eleven years. In the absence of tools other than the pick and shovel, and of effective ven-

tilation, only the unsparing use of slave labor could, we should imagine, have made such a feat possible. There were no Board of Trade inspectors around in those days.

The invention of gunpowder carried the art of tunnelling a long step forward, but it was not until the nineteenth century that engineers learnt how to pierce soft ground, requiring support as soon as excavated. The arrival of the railway made it necessary to learn this lesson. Then came the invention of the powder-drill, and very strong explosives, which enabled engineers to pierce Mont Cenis, the Arlberg, the St. Gothard, and the Simplon tunnels, and the introduction of the "shield" principle by Sir Isambard Brunel (for use in water-bearing strata), since developed to a high pitch of perfection.

CLASSES OF TUNNELLING.

For convenience' sake we may classify tunnels under three headings:—

A. Tunnels through hills and mountains.

B. Tunnels immediately below the surface of the ground—for example, the New York and Boston Subways, and the Metropolitan Railways in London and Paris.

C. Submarine tunnels, carried under a river, and very low-level tunnels such as the "Tube" railways in London.

Though the methods distinctive of one class may be, and are, on occasion applied to another, we may associate the first class with a masonry lining built as fast as the excavation proceeds; the second with the "cut and cover" system; and the third with the shield forced forward through rock, gravel, or sand, to make a way for a continuous lining of iron or concrete.

MOUNTAIN TUNNELS.

When a hill or mountain has to be pierced, the engineer's first task is to gather as full information as possible about the nature of its interior. The services of experienced geologists are employed, and actual samples of the strata through which the tunnel has to pass are obtained by the *diamond drill* (Fig. 199), a steel cylinder armed with low-grade diamonds at its lower or cutting edge, which as it rotates

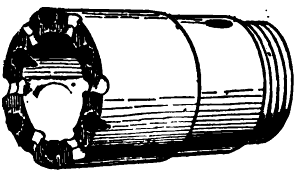


FIG. 199.—The head of a diamond drill, used for drilling deep test-holes in the earth. The black patches are diamonds set alternately on the outside and inside edges of the cutter. Their intense hardness enables the drill to grind its way through the toughest rock. The hollow core cut by the drill serves as a specimen of the strata pierced.

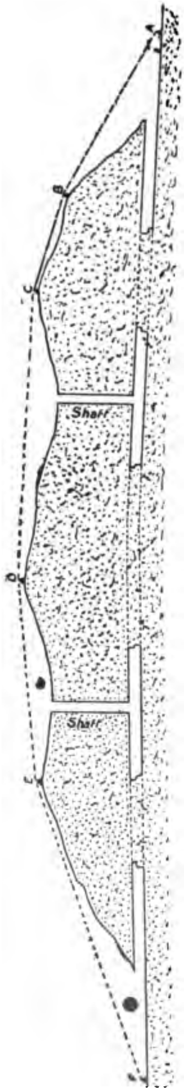


FIG. 200.—Section of a tunnel driven from both ends and from intermediate shafts simultaneously. The dotted lines over the hill are above the centre line of the tunnel.

pierces through the hardest rock with ease. From time to time the drill is lifted and the core which it contains is extracted for examination.

SURVEYING.

The next process is to establish the exact centre line of the tunnel and the points from which observations may be made periodically to keep the workmen on the correct line. In the case of a hill accessible at all parts the process is simple enough for a rectilinear tunnel. In Fig. 200 we see successive observation points, A, B, C, D, E, and F, carried over the hill in a straight line by means of a theodolite, immediately above the path of the tunnel. For the Mont Cenis, St. Gothard, and Simplon tunnels the line was established by the indirect and much more complicated method of survey triangulation.

At each end of the tunnel-to-be two permanent pillars of masonry are set up. The theodolite is placed on the one farthest from the entrance and sighted through a slit in a plate on the other on to an illuminated point in the tunnel at the "face," adjusted to be in line. As the tunnel advances another station is made in the tunnel, the theodolite is taken inside, sighted back to the original station, and turned vertically through half a circle so as to sight forward on the same line. As required, other stations are obtained in like manner. The utmost care must be taken to avoid errors, and that it is taken is proved by the wonderful accuracy with which the headings driven from opposite ends generally meet. In "Railroad Construction," the author, Mr. W. L. Webb, C.E., gives some interesting figures by way of illustration. The Musconetcong tunnel is about 5,000 feet long. When the headings met the error in alignment was found to be only half an inch, and the error in level only about one-sixth of an inch. In the Hoosac tunnel, 25,000 feet long, the errors were even smaller.

Where circumstances permit and render it advisable, shafts are sunk at points on the central line of the tunnel, and headings driven from the bottom

in both directions. In the case illustrated by Fig. 200, six parties of workmen would be able to operate simultaneously. For very long tunnels through mountains towering thousands of feet overhead, shafts are out of the question, and the working faces are reduced to two in number.

TRANSFERRING THE CENTRE LINE DOWN A SHAFT.

The transference of the centre line down shafts is usually effected in the manner illustrated by Fig. 201.

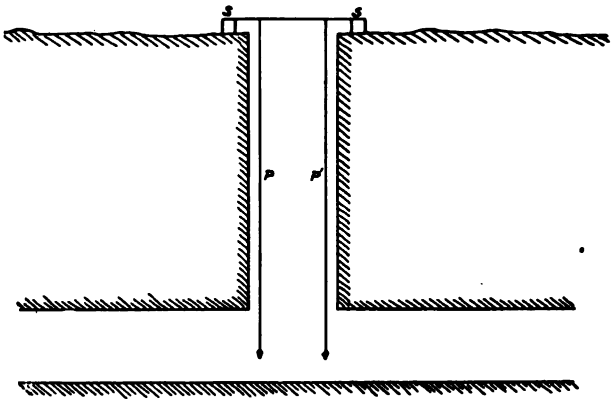


FIG. 201.—

Two pillars, s s, are set up on the centre line and correctly marked. From a wire strung tightly between the marks hang two long plumb lines, P P, with

the "bobs" steadied in pails of water or oil at the shaft bottom. These two plumb bobs serve as guides for carrying the centre line into both the headings.

OPERATIONS UNDERGROUND.

The method of excavating a tunnel depends upon the nature of the stratum penetrated. Where rock and other hard substances have to be dealt with, blasting is used to advance the "face," as the end of the tunnel is called, while pick and shovels suffice for soft materials. The section of the tunnel is usually arched, and a lining of masonry is built in wherever there is danger of the crushing in of the roof and sides, or of an irruption of water, the section being made extra large to allow room for the timbering inside which the masonry is built. The timbers are then pulled forward from between masonry and "ground," and the space filled in with stones, concrete, etc.

There are several systems of excavating a tunnel to full section or "profile," of timbering, and of lining. In some systems a small pilot tunnel is usually run well ahead of the main work, either just under the line of the roof, in which case it is termed a *heading*, or just above the bottom, as a *drift*. The heading

or drift is generally enlarged to the full section by gangs following behind the advance workers. In Fig. 202 are six diagrams to illustrate the English, American, Austrian, Belgian, French, and German systems, each of which is suited to special conditions and is employed only in the country of its origin. The numbers in each diagram indicate the order in which the slices of the section are removed. The English begins with a heading and a drift. The heading is then enlarged on both sides to complete the arch; and extended downwards to meet the drift. Finally the two side ledges are removed. In the American system one top heading and two bottom drifts are driven first and the central core is removed last. The English, American, and Austrian systems are alike in excavating the full section before the masonry lining is commenced. In the French and Belgian the arch is built in at once and supported temporarily while excavation is completed and the side walls are added. The German system excavates for the side walls, builds them up, and then excavates for the arch, the solid core not being removed until the lining is practically complete. This method has the disadvantage of compelling the excavators and masons to work in a very cramped space. An invert, or shallow inverted

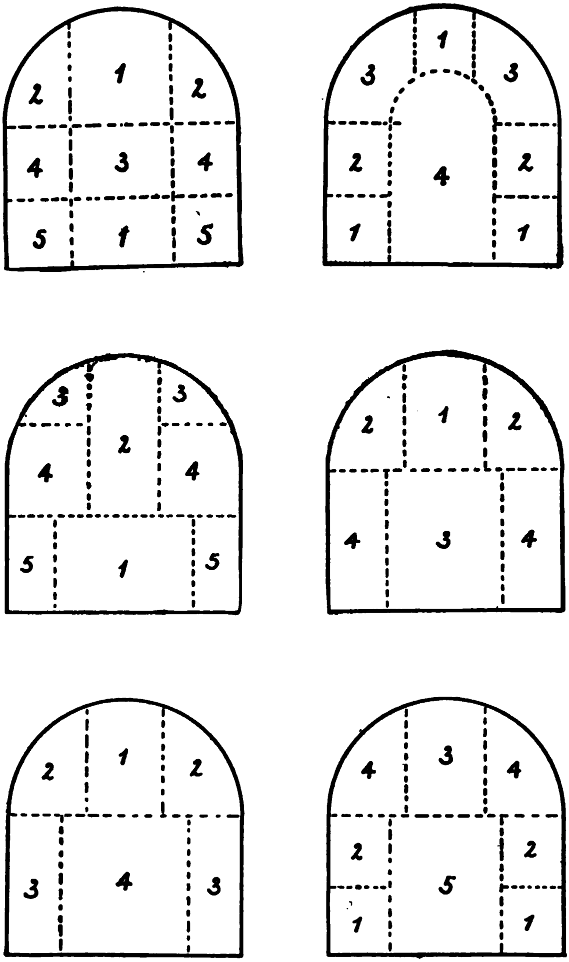


FIG. 202.—Diagrams to show the English, American, Austrian, Belgian, French, and German methods of enlarging a tunnel heading to full profile. The numbers in each case indicate the order in which the slices are removed.

arch, is built from wall to wall at the foot, where there is danger of the floor rising.

THE SIMPLON TUNNEL,

as the longest tunnel in existence and one of the most difficult to make, deserves our special attention. It is a double tunnel with two parallel tunnels 56 feet apart from centre to centre, one for each track. At present only one tunnel is finished and in use, but a gallery for the other was driven right through

Fig. 203.—Section of the Simplon Tunnel. The tunnel rises towards the centre to give drainage by gravitation.

and connected at intervals with the first by cross headings to assist in the transportation of materials and the ventilation of the workings. Operations commenced in November, 1898, and on January 25, 1906, the first train passed from Italy to Switzerland, with the King of Italy on board. The total cost of the completed tunnel and parallel gallery was £3,200,000, equivalent to £148 per lineal yard.

To make holes in the face for the blasting charges the Brandt rock drill was employed. This machine consists mainly of a small double-cylinder hydraulic

motor to rotate the drill proper, and a hydraulic ram to press the drill hard against the rock. The drill is a hollow tube with three or four cutting teeth at the end. The water escaping from the engine passes down the centre of the drill and keeps the edge cool, besides scouring away the débris. In hard rock this drill will sink a hole 39 inches deep in about twenty minutes.

Ten to twelve holes, distributed over the face of the drift, having been made, the charges and fuses were inserted and the floor of the drift was covered with steel plates from which the splintered rock could be shovelled very easily. The workmen then withdrew all tools and other things liable to damage by the explosion, and lit the fuses. Immediately after the discharge, a valve was opened in the tunnel and five jets of water allowed to play on the rock, to lay the dust and clear the air. Then all the débris was shovelled into trucks and taken away to give room to the drilling machines, and the roof and side walls examined with picks to discover any loose and dangerous fragments. The rate of advance in a drift with a section of 59 square feet averaged about 18 feet per day. On the Italian side, where the rock was hard and reliable "break-ups" were made every

50 yards, and top-galleries driven from them in both directions. Fig. 204 shows a drift, C, from which

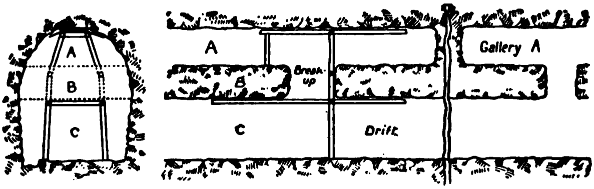


FIG. 204.—Cross and longitudinal sections of the Simplon Tunnel, showing a *drift*, C, and galleries or *headings*, A A, driven from the break-ups.

break-ups have been made, and the galleries A A A driven right and left. The section (on the left) illustrates the timbering of the drift and galleries when first made, and the dotted lines the position of the intermediate ground, afterwards broken away. In Fig. 205 we have the fully-developed timbering of the tunnel, ready for the masonry. Steel "centres" were employed in the Simplon tunnel to support the

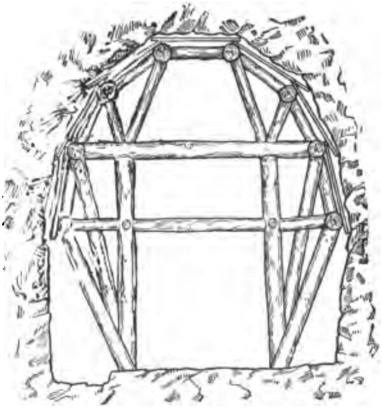


FIG. 205.—Fully-developed timbering in the Simplon Tunnel, inside which the masonry lining is built. *Polling boards* are placed between the timbering and the ground.

masonry arch during construction, as being more easily fixed and less damaged by frequent moving than wooden ones.

VENTILATION.

During the piercing of the St. Gothard in the seventies no fewer than 800 of the workmen died, mainly through the lack of proper ventilation in the galleries, and for means of keeping down the dust raised by the drills. In the Simplon Tunnel the arrangements for ventilation were excellent, twenty-five cubic feet of fresh air being supplied to the workmen for every one blown into the St. Gothard. The current of air was strong enough, we are told, to take a man's hat off; and as for the dust, it was kept down in the manner already described. It is satisfactory to be able to add that during the eight years of work on the Simplon, only 60 men lost their lives from all causes.

In the heart of a mountain the temperature is much higher than that of the outside atmosphere, the heat increasing with the depth of the rock overhead. The maximum rock temperature—133° Fahrenheit—in the Simplon Tunnel was encountered at a point about 7,000 feet below the summit of the mountain.

This would have made things intolerable for the workmen had it not been tempered by huge quantities of cool air driven by fans through large pipes up to the face, and by water-sprays from pipes jacketed with charcoal, to prevent the water becoming heated during its passage up the tunnel.

DIFFICULTIES ENCOUNTERED.

Towards the end of 1901 the advanced gallery on the Italian side pierced a soft stratum, which crushed heavy timbering like so much matchwood. The way was cleared out again, and steel girders used in conjunction with wooden baulks 20 inches square. Even these yielded under the pressure. As a last resource the spaces between the beams were filled in with quick-setting concrete, which stood the strain while a very thick masonry lining was built, in spite of great difficulties, inside the temporary support.

As a result of this delay the Swiss got well ahead of their Italian rivals, and reached the centre point while the latter were still working their way uphill. In order to save time, they decided to drive the galleries downhill towards Italy to meet the other party. Then they unfortunately tapped some extremely hot springs, which ultimately compelled them

to retire, after having fixed strong iron doors in the headings to hold back the water.

The work was now definitely stopped on the Swiss side, and some people prophesied that the completion of the tunnel was impossible. But the Italians pushed on, and at last listeners in the Swiss heading heard their drilling-machines at work, though half a mile of rock remained to be penetrated. Hopes revived. Then the Italians met the hot springs that had given the Swiss so much trouble, and in spite of all efforts to keep down the temperature by mixing cold water with the hot, work on the main tunnel had to be stopped. The engineers refused, however, to own themselves beaten, and continued the gallery of tunnel No. 2, with the object of getting round the flank of the springs, which, owing to the nature of the rock, they were fortunately able to accomplish. Then they drove a cross-cut to the line of tunnel No. 1, and worked back till they met the abandoned heading, and so were enabled to push on with greater vigor than ever. On February 23, 1905, only 5 metres of rock remained unpierced; and next morning a blasting charge released the hot water imprisoned behind the iron doors in the Swiss heading. "The meetings of the headings at once

Fig. 206.—A very sharp curve of 150 feet radius, driven with a shield, in the Hudson River Tunnel.
(Photo, "Scientific American.")

proved the accuracy with which the work had been executed, but it lacked the fervor of delight usual on such occasions, as in this case it was a meeting of miners on the one side and hot water on the other. The last 245 metres of the gallery had occupied nearly six months in execution, owing to the unprecedented difficulties encountered.*

The headings met with an error of but 8 inches laterally and $3\frac{1}{2}$ inches vertically. The total length was found to be 31 inches less than had been anticipated. Considering that these errors are distributed over $12\frac{1}{3}$ miles, their smallness is remarkable.

By a noteworthy coincidence the Simplon Tunnel was opened almost exactly a hundred years after the completion of the military road over the Simplon Pass by Napoleon—the first to promote the interests of peace and civilization, as the second was to make easier the passage of invading armies.

Trains are hauled through the tunnel in 18 minutes (= 42 miles an hour) by electric locomotives. Tunnel No. 2 is being enlarged by Messrs. Brandt, Brandau and Co., the contractors for the first, and in due course the second track will be laid.

* F. Fox on the Simplon Tunnel, "Proceedings of the Institution of Civil Engineers."

OTHER FAMOUS MOUNTAIN TUNNELS.

The Mount Cenis and St. Gothard tunnels are household words, and, though eclipsed in point of length by the Simplon, are in their way equally remarkable, as the obstacles to be overcome in the construction of all three were very similar. The Mount Cenis tunnel, like the St. Gothard, has a section large enough to take a double track. It measures $7\frac{5}{8}$ miles from end to end, and took thirteen years of boring at an average daily rate of about $2\frac{1}{2}$ yards. It was opened to traffic in 1871, and gives south France direct communication with Turin, Genoa, and Brindisi in Italy.

The diversion of trade to this route put the Swiss on their mettle, and in 1869 they decided to pierce the Alps at the St. Gothard Pass, about 130 miles north-east of the Mont Cenis tunnel, and so obtain a quick route to Italy. The Swiss, German, and Italian governments, all of which would benefit, subscribed the necessary money (£2,327,000) between them, and work was begun in 1871 on a tunnel $9\frac{1}{4}$ miles long. Here for the first time a locomotive driven by compressed air was used to remove earth and broken rock from tunnel headings, and the type

of air power-drills employed was a great improvement on those used for boring the Mont Cenis, though inferior to the Brandt hydraulic drill. But the ventilation left much to be desired, and the heat in the tunnel was such as to kill many horses, and, as we have already noticed, cause great mortality among the workmen. The work occupied eleven years, the tunnel being opened on June 1, 1882. Some remarkable engineering feats had meanwhile been done on the lines approaching the tunnel at both ends, notably the boring of thirty-three tunnels, eight of them of the helicoidal, or corkscrew type, a mile long each.

The success of the St. Gothard Tunnel roused the emulation of the Austrians, who greatly desired an independent route to Paris, *viâ* Bâsle, through the Arlberg in the Austrian Tyrol, the watershed separating the basins of the Rhine and Danube. The railway pushed from Innsbruck to the Rhine is a fine piece of work throughout, and its most striking feature is the Arlberg Tunnel, 6½ miles in length, begun in 1880, and completed five years later. The Brandt hydraulic drill here proved its superiority for tunnel work over the air-driven percussion-drills used in the Cenis and St. Gothard bores, and the expedi-

ency of spraying the working face with fine water jets immediately after an explosion was established. In fact, the engineers learned several valuable lessons in tunnel-driving, which they were able to turn to account in the Simplon Tunnel operations.

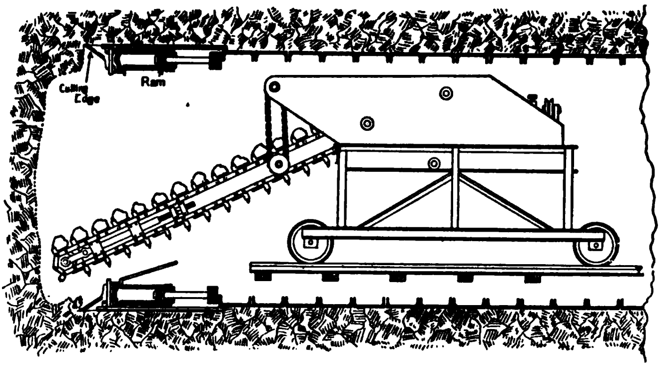


FIG. 207.—A Thompson electric excavator, used in "tube" tunnels. The front arm round which the buckets pass can be moved in all directions, so as to reach the whole of the face.

The Simplon, the most recently completed of the Alpine tunnels, lies between the Mont Cenis and the St. Gothard, with both of which it competes successfully, thanks to its gentle gradients and its less altitude above the sea. It will in turn soon be threatened, as the French, smarting under the loss of traffic over the Mont Cenis route, have opened negotiations with the Italian government for a rail-

way to join Aosta in Italy with Chamonix in France, passing right under Mont Blanc in a tunnel $11\frac{1}{5}$ miles long. This railway would become the high-road for traffic between England and Brindisi, *viâ* the northern French ports and Geneva, and divert a great deal of that which now uses the Swiss lines and the Simplon and St. Gothard tunnels.

So the peaceful battle goes on between nation and nation, and we may expect to see the Alps pierced again and again, and still again, in the desire to reach Italy and her Mediterranean ports.

A project which threatens to eclipse all existing tunnels is one for driving a canal tunnel through the high ground between the Rhone and Marseilles. The tunnel is to be $4\frac{1}{2}$ miles long, 70 feet wide—to allow two large barges to pass one another at any point—and 50 feet high. The amount of material to be removed would greatly exceed that shifted in any tunnelling feat yet accomplished.

THE "CUT AND COVER" SYSTEM

of tunnelling is used mainly for shallow underground railways in towns, and for aqueducts and sewers. Where traffic will not be impeded, a single trench of the required width is excavated, the tunnel built

in it length by length, and the surface made good by ramming down earth on the arch. In busy streets this simple method is impracticable, and it becomes necessary to carry out the work in some manner which shall cause as little inconvenience to the public as possible.

One of two alternative methods, or a combination of both is generally used under such conditions. We may notice them briefly.

The Longitudinal Trench Method.—Two narrow parallel trenches are dug, one on each side of the road, for the side walls, which are built in them up to the commencement of the arch. The surface is then removed in strips to the centre line of the road, and half the arch built and covered; next, the other half is cleared, and the remainder of the strip of arch built and covered in. One-half of the road is thus kept open always for traffic. Finally, the core enclosed by the walls and arch is excavated in the usual manner from either end of the tunnel and through shafts left at intervals for the purpose. In some cases the arch is built across at once in strips, the road being closed during the least busy hours of the twenty-four.

The Transverse Trench Method.—In this the road

is excavated to full depth across the street in slices during the night, and covered over with beams and stout planks to carry the day traffic. In the day-time the masons build up the masonry under this temporary roof. This method was largely employed for the Boston Subway and the New York Rapid Transit Subway. In very busy streets, where the traffic was heavy at night as well as by day, all the work had to be done from below. Small drifts were driven for the lower parts of the side walls, whereon the workmen laid rails to carry a movable shield, to support the roadway while the earth was removed and the masonry laid. The mention of a shield prepares the way for our next chapter.

Chapter XX.

SUBMARINE TUNNELS.

The Severn tunnel—The shield system of tunnelling—Construction of the shield—The front-end, body, and tail—Shields with air-locks—The Rotherhithe tunnel—Sinking the shafts—Driving a "pilot" tunnel—The big shield at work—Advancing the shield—Guiding the shield—Accuracy with which the shield is steered—Some instances—Fighting water—Securing a tunnel with piles—Big tunnelling projects—The Harlem River tunnel—Building the caisson—Constructing the tunnel under the caisson—Another method tried successfully—The Detroit River tunnel—A double-barrelled tube sunk by sections—How it was done—Connecting up the sections—Covering the sections with concrete.

THE majority of submarine tunnels have been driven under a river at a point where the influence of tides is felt, hence their name. There are nine tunnels under the Thames in the London tidal reaches, and in New York a dozen or more tunnels under the Hudson and East Rivers connect Manhattan Island with New Jersey and Long Island.

In submarine tunnelling the engineer has most to fear from the inroads of water from the river above,

which is inexhaustible, and cannot therefore be run dry like many a spring tapped in the heart of a mountain. The strata through which he has to burrow are often silt, clay, gravel, and other treacherous materials. He cannot employ drainage by gravitation, as the submarine tunnel falls towards the centre (see Fig. 211), and such water as does find its way in must be removed by pumping.

The Severn Tunnel, driven under the river of that name in the years 1873-85, is a notable instance of a submarine tunnel excavated, timbered, and lined in the same way as the Simplon and other mountain tunnels. In spite of the fact that the engineers kept well below the river bed they were greatly hampered by water, which on more than one occasion completely drowned the headings, and was checked only with the help of an expert diver.

As the length of a tunnel must be increased with its dip, gradients being equal, its roof is kept as near the river bottom as possible, and the engineer has generally to pierce a water-bearing stratum at one or more points. The difficulty of preventing the caving of the ground and the inflow of water led the famous Isambard Brunel to introduce

Fig. 208.—Dismantling a shield. Note division of the shield into six compartments.
(Photo, F. Marsh, F.R.P.S., Clifton.)

THE SHIELD SYSTEM OF TUNNELLING

for the construction of the first Thames Tunnel, opened in 1843. This system has since been much improved by Greathead and other engineers, and is generally used for the construction of deep-level tunnels such as the London "tubes," as well as for submarine. The lining of such tunnels is of iron rings, built up in segments, sometimes reinforced inside with concrete.

CONSTRUCTION OF THE SHIELD.

Tunnelling shields are of several types, adapted to meet different conditions. The simplest form is a cylinder of steel plates, absolutely smooth on the outside, its "front end" furnished with knives set close together round the edge; or the plates of the edge itself are made to form a huge circular cutter of wedge-like section (see Fig. 208). Some feet behind the cutting edge is a stout *diaphragm*, or bulkhead, to prevent the cylinder being distorted by pressure. The diaphragm has a large hole or holes in it, through which the stuff dug from the working face is removed. In some cases the diaphragm is replaced by strong girders, and, where the shield is very large,

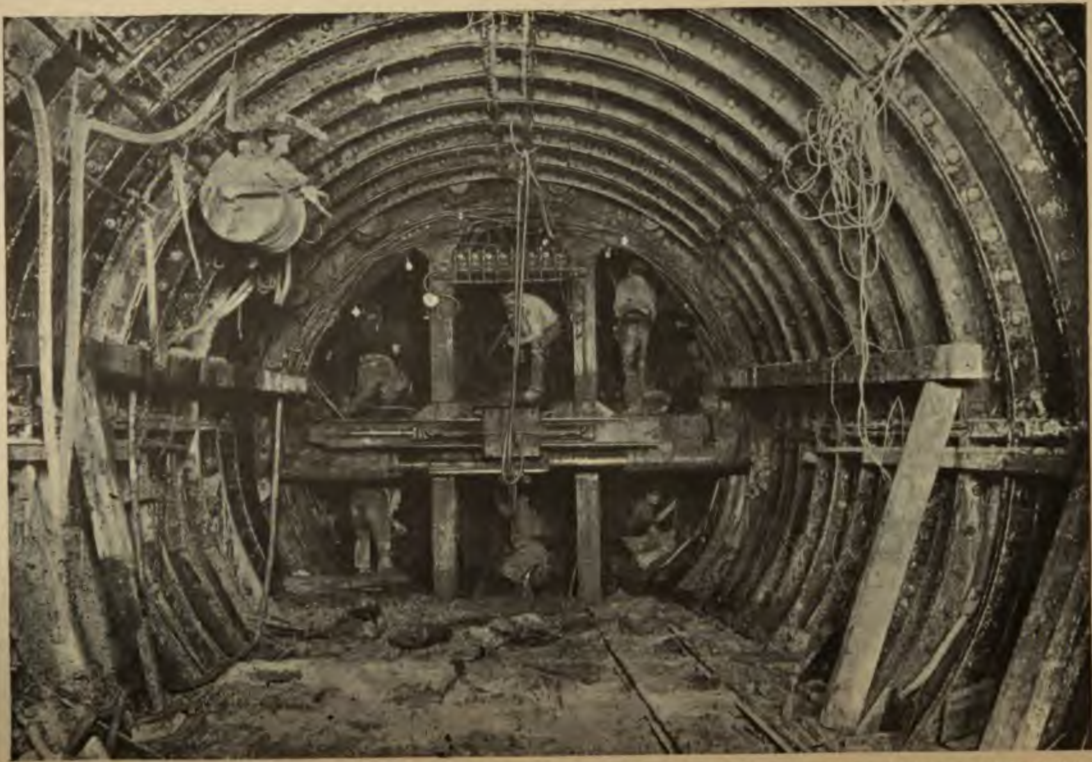


FIG. 209.—Attacking the "face" in a shield. The ends of the hydraulic rams which advance the shield are plainly visible.
(*Photo. F. Marsh, F.R.P.S., Clifton.*)

the front end is divided up into compartments by vertical and horizontal partitions, so that the men may attack the face at several levels simultaneously. (Fig. 209 is an example of a shield thus divided into six compartments.)

The *body* of the shield contains a number of hydraulic jacks arranged at regular intervals inside the lining (see Fig. 209), their cylinder ends attached to a stout ring, and their rams all pointing towards the rear end. Here, too, are stationed the pumps, motors, and machinery for getting the segments of the rings into place.

The rear end, or *tail,* is at least as long as two rings of lining, so that it may rest on the last completed ring, and support the earth while another ring is added.

Where unstable and treacherous materials have to be pierced and where water is present, a shield of the type shown in Fig. 210 is used, in conjunction with compressed air. The front-end is shut off from the tail by a double diaphragm fitted with doors, so as to form a number of air-locks through which men and the excavated débris pass. On every floor of the shield is a safety-chamber, with an air-tight steel curtain, H, extending downwards from the floor above

so as to partly separate it from the face. If water suddenly invades the shield the workmen take refuge behind these curtains —above the bottom of which the water cannot rise—and make their way out through the air-locks.

In some tunnels driven by compressed air, the shields are open, and the air is retained by a bulkhead built some distance away in the tunnel, safety-chambers being provided at intervals between it and the face. The reader must understand that no two tunnels are driven under exactly the same conditions and that therefore engineers have to be constantly adopting new expedients to meet novel difficulties.

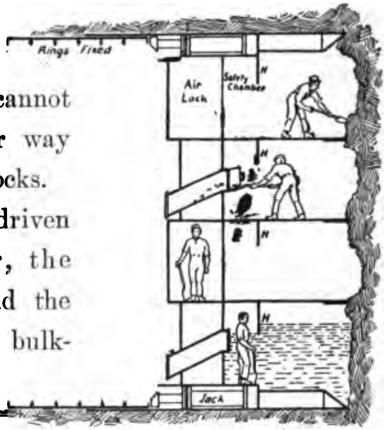


FIG. 210.—Section of a shield with air-locks, for use in water-logged strata. At the bottom is seen a man taking refuge in a safety-chamber from an inrush of water.

Submarine railway tunnels and "tubes" are made in pairs, one for each track. Vehicle and footway tunnels, such as the Blackwall and Rotherhithe under the Thames, are single tubes of very large diameter.

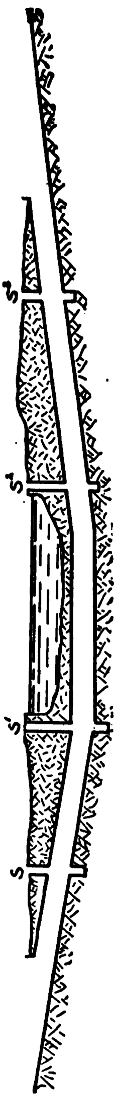


Fig. 211.—Horizontal section of the Tunnel under the Thames.

THE ROTHERHITHE TUNNEL

has a total length, including approaches, of 1$\frac{1}{3}$ miles, and an outside diameter of 30 feet. It connects Shadwell on the north bank with Rotherhithe on the Surrey side.

Of the total length 3,580 feet were shield-driven and lined with iron rings 2 inches thick; 1,140 feet were constructed on the "cut and cover" principle, and the balance of the work is represented by open approaches. Referring to Fig. 211, which shows the tunnel in section, you will notice that there are four shafts—s, s^1, s^2, s^3. Between shafts 3 and 4 the tunnel runs on a curve of 800-foot radius. Between shafts 2 and 3, and between 2 and 1, it is straight, there being a slight angle in the line at shaft 2. Much of the land tunnelling was done under houses and other buildings, including the South Metropolitan gas works, but without causing any disturbance of the ground or of the foundations above.

Operations began with the sinking of the four shafts, the two deeper ones of which were located as near the river as possible. Each shaft was sunk by a circular vertical steel caisson, having two concentric shells, 60 and 50 feet in diameter, braced together. At the bottom the inner shell was tapered outwards to join the outer and form a cutting edge. Thirteen feet above this edge was a permanent floor of steel plates attached to cross girders, and above the level of the floor were two circular openings in the caisson, 32 feet across, one on each side, on the line of the tunnel. During the sinking of the shaft these were closed by timber bulkheads of the same curve as the outer shell.

Men working under the floor excavated a path for the caisson, which was added to above as the cutting edge, impelled by the weight of the steel mass and of the concrete filled in between the two shells, bit its way downward. When the full depth had been attained, the cavity below the floor was made solid with the same material.

As soon as shaft No. 3 was complete and a temporary air-tight floor had been constructed above the caisson openings, so that compressed air might be used, a shield, 11 feet 8½ inches in diameter, was

erected at the bottom, and started off on a journey under the river, to cut a "pilot" tunnel, from the driving of which information about the nature of the ground could be learned. This shield made its way without much difficulty to within 50 yards of shaft No. 2, when it was stopped. Progress was greatly expedited by the use of an excavating machine attached to the front of the shield—a wheel revolving across the face of the heading three times a minute, scooping out deep grooves and delivering the material into cars by endless conveyors. This machine is the invention of the contractors, Messrs. Price and Reeves. Another type of digger—the "Thompson" is shown in Fig. 207. It was used with success in the central London "tubes."

While this small tunnel was being driven and lined, a huge shield 30 feet 8 inches across and 18 feet long had been erected in shaft No. 3. Horizontal and vertical partitions divided the front into sixteen compartments. For advancing it, forty hydraulic jacks with 9-inch (diameter) rams were installed, able to give a 5,000-ton shove when all worked together. From the rear end projected a stage 50 feet long, carrying pumps, lifting tackle, and other mechanism. This monster now made its way out through the

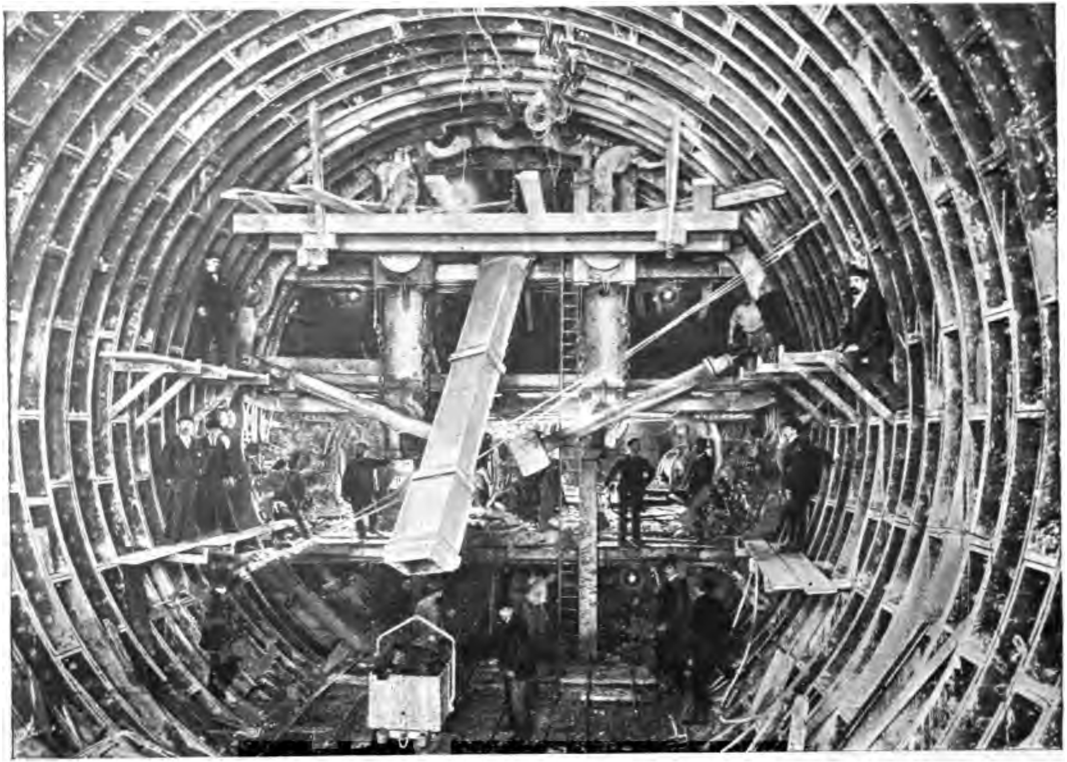


FIG. 212.—At work in a station tunnel, South London Tube Railway.
(*Photo, E. Milner.*)

southerly opening in the caisson, and followed the track of its smaller predecessor running on the same centre.

To give the shield a push-off, temporary rings are erected in the shaft and kept there until several rings of permanent lining have been placed. The latter rings, each weighing 20 tons, are compounded of sixteen segments, with flanges 14 inches deep on all four edges, by which they are attached to one another and to the segments of the two adjacent rings. To lift them into position powerful presses were employed.

Every segment contained a hole tapped for a screw plug, through which liquid cement was forced to fill up the small annular space between the lining and the ground, due to the shield being of somewhat larger diameter than the lining.

The process of advancing a shield is as follows. While the last ring is being built up, the rams of the hydraulic jacks are drawn fully into their cylinders, so as to be out of the way. The ring finished, high pressure water is turned into the jacks, and all the rams push simultaneously against the foremost flange of the lining, driving the cutting edge some distance into the unbroken ground. The workmen then attack

Fig. 213.—Lifting the segments of a ring of lining into position.
(*Photo, F. Marsh, F.R.P.S., Clifton.*)

the face except near the edge; and when a vertical slice has been removed, the jacks give another push, and so on, until the rams have made their full stroke. Then they are withdrawn, and the next ring is erected.

GUIDING THE SHIELD.

The jacks have to steer the shield as well as push it. In rounding a curve to the right, the left-hand jacks are made to do more work than those on the right at each advance, and conversely, if the curve bears to the left. To get a down-grade line the top jacks do most of the pushing; for an up-grade, the floor jacks, though when the line has once been struck all jacks take an equal share.

Figs. 214 and 215 serve to explain how a shield is guided laterally and vertically. Of course, all calculations are based upon careful observations made with the theodolite, and checked frequently to prevent errors creeping in, as submarine tunnels driven from two or more points by shields moving towards one another should meet absolutely accurately.

To take lateral guidance round a curve first. Two file marks are made on the lining (Fig. 214), on an imaginary line drawn from the centre of the circle of which the curve is a part. Two rods, N N, are

applied horizontally to the sides of the tunnel, one end fixed at the file marks, the other end merely supported. On these rods marks are made at distances from the file marks proportionate to the length of the radii of the inner and outer curves of the sides of the tunnel; thus in the example given (Fig. 214) the distances would be in the proportion of 26 to 29.

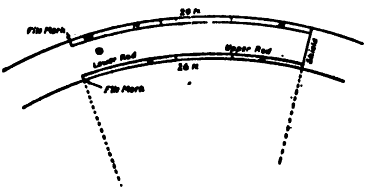


FIG. 214.—Diagram to explain how a shield is guided round a curve by measuring-rods.

Upper rods, M M, marked to feet and inches, are laid on N N, and their forward ends kept pressed hard up against the shield when the jacks are moving it forward. By comparing the readings on the upper rods relatively to the marks on the lower rods, the workmen are able to regulate the advance and maintain the curve.

To guide the shield horizontally or on the slope an arm, S (Fig. 215), of a certain length is fixed to the diaphragm. From this hangs a plumb-line. During an advance a graduated "plumb-stick" L, is held horizontal by a workman against the shield. If the drive is to be perfectly horizontal, the plumb line

must lie opposite the zero mark on the plumb-stick; if upwards, outside the mark; if downwards, inside the mark, by an amount carefully calculated by the engineer in charge to give the requisite gradient.

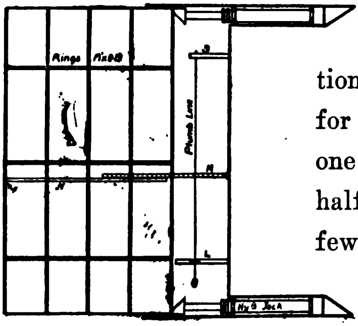


FIG. 215.—Section of a shield, showing measuring-rods, N, M, and plumb-line.

From time to time he leaves written instructions of the following kind for the foreman: "*Lead*, one inch *right*," "Plumb, half-inch *up*." At every few rings observations of level and right or left deflection are taken by instruments.

The accuracy with which these submarine tunnels are driven appears all the more extraordinary when we consider that they are not rectilinear, and often include some awkward curves. Sir Douglas Fox, in a speech at the Institution of Civil Engineers, gave an interesting example of exactness in calculation. He said: "In the case of the Mersey Tunnel it was impossible to place the shafts on the line of the tunnel, and there were curved headings leading from one of the shafts to the tunnel. Consequently the setting out was complicated. It was rendered still

more difficult by the fact that the lines were set out in a drainage heading which was a continuous shower-bath. It was exceedingly difficult even to walk along the heading, and still harder to perform any delicate operation in it. In that case, when the two headings were about to meet, it was decided that the mayors of the two towns should come and shake hands in the middle. He ventured to suggest to the resident engineer that a bore hole should be put in [from heading to heading] before the mayors came, at which he was offended, saying that it was unnecessary, as he was quite certain where he was. However, Sir James Brunlees and himself insisted upon having it, with the result that a bore-hole was put through from one side in the centre line, and the end of the bore-hole struck the centre line on the other side." On one of the London tubes where there were six meetings, five of them were less than $1/4$ inch out!

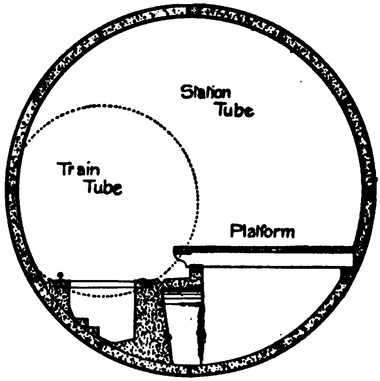


FIG. 216.—Section of station tunnel, Central London Railway, showing two train tubes.

On very sharp curves the lining rings have to be tapered towards the inside; on gentle curves the V-shaped spaces between parallel rings are carefully packed and made watertight with metal, cement, wood, or some other material.

FIG. 217.—

To return to the Rotherhithe Tunnel. The big shield eventually found its way to shaft No. 2, through which it passed on an upward grade till shaft No. 1 was reached. Meanwhile a second shield of extra solid design had been erected in shaft 3, and driven north-east on a curve to shaft 4. It remained to line the iron tube with a thick coating

of cement, extending 4 inches beyond the flanges, and face it with white glazed tiles; also to build a continuous arch along the bottom of the tunnel, to carry the road and sidewalks, as well as serve as a subway for electric and water mains. The central carriage way is 16 feet wide, and each of the sidewalks 4 feet 8½ inches wide. From end to end the tunnel is lighted by three rows of electric lamps.

For this great task were required: iron, 27,000 tons; steel, 4,000 tons; cement, 30,000 tons; besides 5,000,000 bricks, 40,000 square yards of asphalt, and 100,000 cubic yards of cement concrete.

FIGHTING WATER.

The making of the sub-river portion of the Rotherhithe Tunnel was not accompanied by any very great difficulties. In the case of the Blackwall Tunnel, the river section of the Baker Street—Waterloo tubes, and several of the New York tunnels, the presence of water required the greatest care in excavation, it being a matter of some delicacy to so balance the air pressure that on the one hand the water might be kept at bay, and on the other there might not be a "blow-out" of river-bed. Such a blow-out on the Hudson River tunnel resulted in the

loss of twenty lives and the abandonment of the work for several years. To prevent disasters of this kind it is sometimes necessary to dump large quantities of clay on the bed of the river above the line of the tunnel, the clay being removed after it has served its purpose. For dealing with very soft material the front of the shield is protected by a bulkhead near the face, with a number of small openings in it, which can be closed by shutters, in some instances so small that the workmen have to do the excavating with their hands.

As a tunnel weighs less than the volume of water which it displaces, there is a tendency for it to float in mud and silt. Some of the New York tunnels are secured against any vertical movement by huge piles driven down by hydraulic power to firm ground through holes cut in the bottom, and attached securely to the lining.

Submarine tunnelling has been so perfected that engineers seem able to cope successfully with all conditions. They are prepared, if called upon, to tunnel under the Straits of Dover and make railway tubes from Scotland to Ireland. The project has even been seriously mooted of burrowing under the Behring Straits, so that one might journey by train

from New York to London, assuming the Channel Tunnel to be already in existence. Considering the

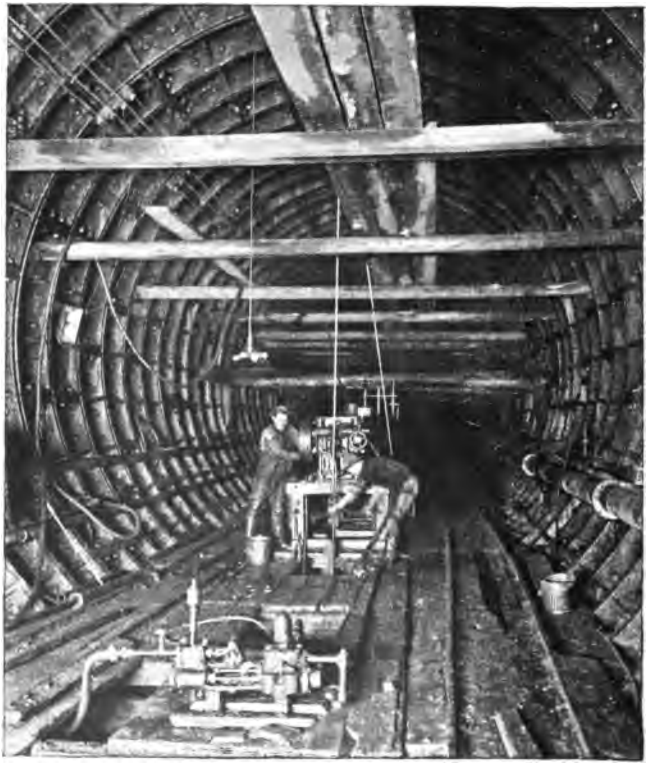


FIG. 218.—Exploring with boring machine, Pennsylvania Railway Tunnel, New York.
(*Photo, Pennsylvania Railroad Co.*)

magnitude of past victories of engineering science, the chief difficulties in the way of any one of these

schemes appear to be financial and political rather than physical; and one should think twice before classing them with "wild-cat" propositions. The "impossible" of to-day is the matter-of-fact achievement of to-morrow.

THE HARLEM RIVER TUNNEL.

Having dealt at some length with the "shield" method of tunnel boring, we may turn our attention to a different system of making a tunnel. A tunnel destined to carry the double tracks of the new Rapid Transit Subway has been taken under the Harlem River, New York, in a novel manner worthy of notice.

Owing to the river bed being of so soft and treacherous a nature that the driving of a tunnel through it at the necessary level would have been attended by the greatest risks, the engineers adopted a plan of their own. This was to construct a watertight gallery in the river bed, and to establish the double-track tunnel inside it. How they carried out their purpose is explained by Figs. 219, 220, and 221.

First a trench was scooped in the river bed on the line of the tunnel. Piles, P P (Fig. 219), were then driven down on each side of the trench to carry

working platforms. The workmen then drove between the platforms several parallel rows of shorter piles P¹ P¹, those on the outside, S P, S P, touching one another so as to form continuous watertight walls of *sheet*-piling, kept in line by horizontal beams bolted

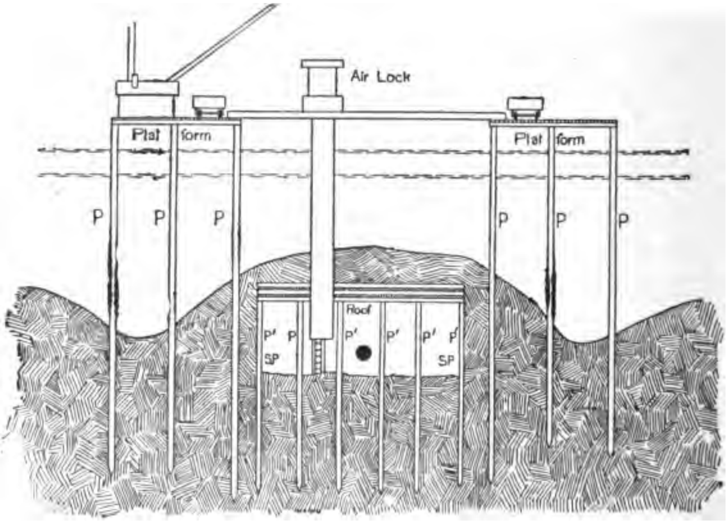


FIG. 219.—Diagram to show section of caisson under which part of the Harlem River Tunnel was built.

along the outside near the top, and connected by cross trusses. Driving the sheet-piling was no easy matter, as lumps of rock occasionally obstructed the points, and blasting had to be resorted to before the pile could be sent home. Moreover, on account of

the size of the piles, each compounded of three beams 12 by 12 inches in section, all tongued and grooved to interlock with the next pile, it was necessary to prepare holes for them with "pilot" piles of steel carrying pipes that squirted high-pressure water out at the tips, and quickly ate a way down through the sand.

When the sheet-piling had been properly aligned by divers, a circular saw suspended from a moving platform spanning the trench was employed to cut off the heads of the piles at a certain level, the saw being gradually raised or depressed as it moved along, so that the exact grade of the tunnel should be observed.

Carpenters now busied themselves in the preparation of a massive timber roof built up of several layers of baulks and planks. This was floated over the short piles in sections, and sunk with its edges resting on the sheet-piling, to which it was attached by angle irons. All joints having been caulked, and bulkheads built at the ends, mud was heaped over the roof, and pumps extracted the water. In order to admit workmen and materials, shafts were constructed from the roof to the platforms, their upper ends terminating in air-locks, as a moderate extra

air-pressure was needed to keep the chamber clear of water.

Under cover of the wooden walls and roof the workmen excavated a rectangular space somewhat deeper than the tunnel. When the floor had been levelled, a thick bed of concreting was laid among the piles (P¹ P¹, Fig. 219), which were then cut off flush with the concrete and spiked to get a grip of a second layer of concrete spread over the first. Segments of the cast-iron lining were introduced through the shafts and bolted together in position on the concrete, which, as soon as the metal-work permitted, was brought up and over the tubes, the sheet-piling shaping the sides of the mass. Fig. 220 shows a section of tunnel at this stage. The removal of the roof, the cutting off of the sheet-piling heads, and the dismantling of the side platforms, so as to leave the waterway clear, completed the work.

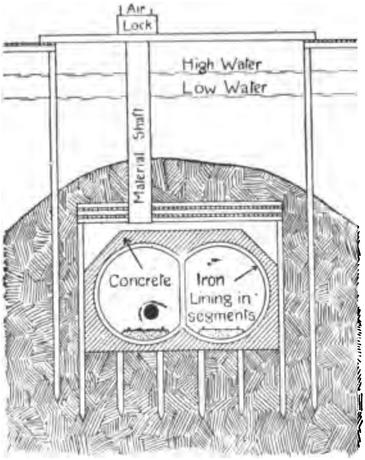


FIG. 220.—Harlem River Tunnel. Section completed inside caisson.

When the tunnel had been partly constructed the engineers decided to modify their system in a manner which is explained by Fig. 221. For the tall piling of Fig. 219 was substituted shorter piling which reached only to the central horizontal line of the tunnel, and the place of a solid wooden roof was taken by sections of the top half of the tunnel itself, previously finished and lowered into position on the piles.

For the preparation of the roof a pontoon was made between the working platforms. Inside this the segments of the iron tunnel rings were assembled and bolted together, until the upper half of the "double barrel" had been formed. A wooden floor was attached to the bottom, and a wooden bulkhead to each of the four semicircular ends, so as to form two watertight chambers. These were covered with concrete to the shape shown in Fig. 221. The pontoon was then sunk in the water till the section floated, and one end of it was removed so that it could be withdrawn from under the section, which had previously been made fast to lifting tackle resting on the platforms.

Valves having been opened, the section filled slowly and sank on the piles, to which divers ad-

justed the edges exactly. The divers, entering the section, attached it to that on the shore side, and screwed bolts through the edges of the iron-work into the sheet-piling on which they rested.

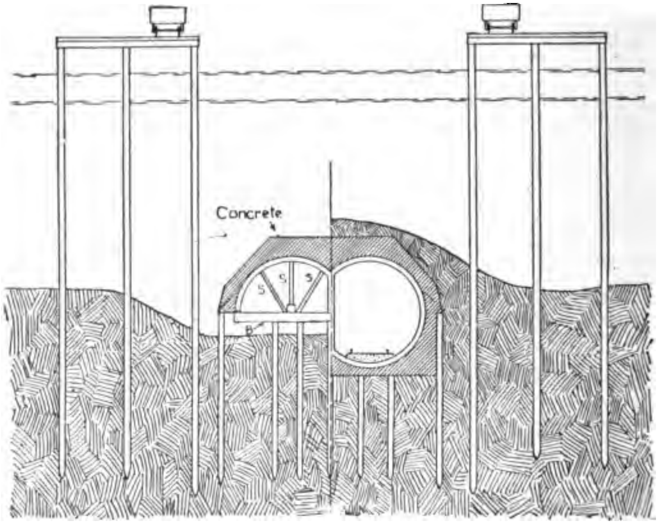


Fig. 221.—Second method used for the Harlem River Tunnel. The top half of the tunnel was lowered on to sheet piling, to form a water-tight chamber, in which the lower half was built.

After all joints had been made watertight the mud was piled over the section to keep it down, and the work of excavating for the lower half of the tunnel proceeded under compressed air, as in the original method. The half rings were attached to their corresponding upper halves, and the space

between the outside, the iron-work, and the sheet-piling was filled with concrete to complete the protecting and strengthening envelope. In Fig. 221 the right half of the section shows a completed tube; the left half, the formation of the roof when first made fast to the sheet-piling. Access for materials and egress for the excavated mud, etc., was, of course, afforded by breaking down the end bulkheads of each section and establishing direct communication with the shore.

This method has proved so satisfactory and expeditious that we may expect to see it widely employed in the future where the natural conditions are suitable. It is not accompanied by the perils of a "blow out," which are the nightmare of workers engaged on the driving of a shield through a treacherous stratum. It has the further advantage that it permits work to be carried on at several points simultaneously, instead of at two only, which is the maximum number possible in a tunnel bored under a river bed, unless expensive shafts be constructed in the river itself. While dredging is done at one place, pile-driving proceeds at another, section-forming at a third, and section-sinking and fixing at a fourth, so that little time is lost.

THE DETROIT RIVER TUNNEL.

The waters of Lakes Superior, Michigan, and Huron pass into Lake Erie through the Detroit River, which for about one hundred miles forms part of the boundary line between the United States and Canada. On the western bank, not far from Lake Erie, is the City of Detroit, and opposite to it, almost at the end of the long Ontario peninsula, stands the Canadian town of Windsor. A good map will show you that several railroads converge on Detroit, which is one of the most important centres of the railroad systems connecting Chicago and the west with New York, the New England States, and Eastern Canada.

Hitherto the passage of the Detroit River has necessitated the use of great ferry steamers, sufficiently capacious to accommodate a complete express train. These ferry boats ply in all seasons, crashing through the winter ice-floes when they accumulate. But under the best of summer conditions the transference of train from quay to boat and from boat to quay means the loss of at least half an hour in the case of an express, and some hours when a long and heavy "freight" has to be handled. In addition to the

expense of delays—for time is money on the railroad as elsewhere—comes that of maintaining the ferry boats and keeping the crossing clear in winter; so that, in view of the rapidly increasing traffic on the Detroit routes, it became imperative to remove the obstruction in one way or another.

The erection of a bridge being put out of court by the boat traffic between the lakes, a sub-river tunnel was the alternative. Mr. Henry B. Ledyard, president of the Michigan Central, prevailed upon his board of directors to authorize a tunnel, the designing of which occupied many months prior to the summer of 1906, when the final plans were adopted.

These plans provided for a double-barrelled tunnel of steel tubes lined with concrete, through which trains would be operated by electricity. The total cost of the undertaking was estimated at $8,000,000, a huge sum indeed, but moderate in view of the great advantages that the tunnel would confer on the railroads making use of it.

We have already seen how tunnels are driven through rock and through the silt and clays of a river bed. We have noticed also the method of constructing the Harlem River Tunnel. This last method approaches most nearly to that adopted for the tunnel

now under consideration; but there is so great a difference between the two that the Detroit River Tunnel, for the scheming of which Mr. W. J. Wilgus was chiefly responsible, affords a gigantic novelty in engineering.

The project was briefly this: to scoop a trench 45 feet deep and 40 feet wide at the bottom across the bed of the river from Detroit to Windsor; in this to lay lengths of huge double tubing, bolt them end to end, and cover them with concrete, clay, and stones, and to join up the extremities of the tubes to tunnels and cuts rising at a gentle gradient to the general level of the adjacent country.

The actual work was done as follows. First, great dredgers scooped out the trench. Floating pile-drivers followed driving piles down till their heads were level with the bottom of the trench, and at such distances apart that the tubes should rest upon them at the desired points.

The tubes, of stout steel plate, are each 23 feet in diameter, and built up in 260-foot sections, the two tubes of each section being connected and surrounded by vertical cross diagrams at intervals of 11½ feet. The Great Lakes Engineering Company were responsible for the steelwork.

Each section, when complete, had its ends plugged with timber to make it watertight, was launched, towed down the river 48 miles to the scene of opera-

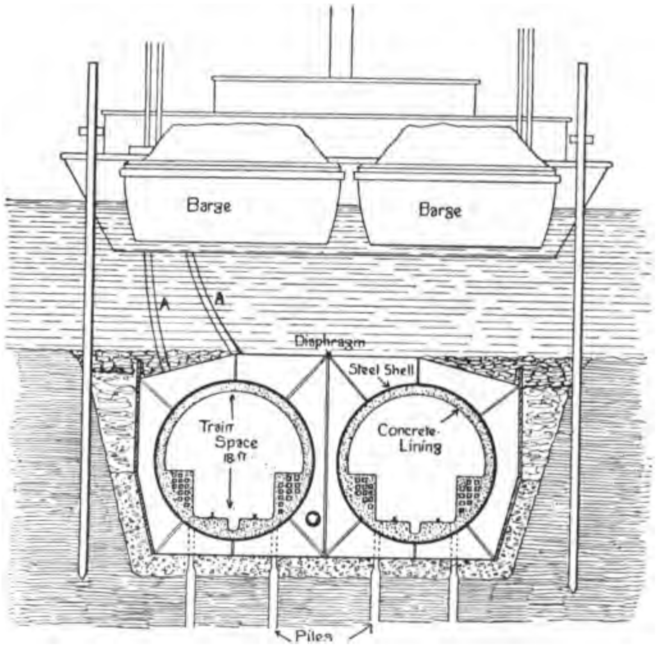


FIG. 222.—Section of the Detroit River Tunnel ready for sinking into trench in the river bed.

tions, and brought to rest exactly over its final position in the river bed. Water was then admitted gradually, and the section sank slowly, its alignment being kept correct by means of the temporary vertical

masts attached to each end. Four cylindrical floats, 10 feet in diameter by 60 in length, assisted the tubes to settle on an even keel, with the diaphragms resting on or over the beams of the piling below. (Figs. 223 and 224.)

Divers now descend 80 feet or so into the water, examine the supports carefully, and where necessary place packings between piles and diaphragms. Their next duty is to connect the newly-sunk section, which we will call A, up to that already in position, B. To effect this a loose sleeve or ring at the end of A is slipped over the end of B, and the flange of the sleeve is screwed up against a flange on B—a thick rubber ring having been first inserted, so as to make a water-tight joint. An internal flange at the rear end of the sleeve is simultaneously brought up against a second rubber ring on the inside of an external flange at the extreme end of A. Between the sleeve and B there is thus enclosed an annular space 18 inches long and 3 inches deep. The water is pumped out of this, and when the joints have been tested to prove their tightness, liquid cement is run in until the space is completely filled.

It is now necessary to cover the tubes over with concrete and weigh them down, protect them from the

action of the water, and stiffen them. As a preparation for the concrete a two-foot layer of gravel is spread over the bottom of the trench, and then tons and tons of concrete are shot down between the diaphragms through tubes leading from mixers floating above. Stout planking, attached to the diaphragms so as to form long wooden walls along the outside of the section, gives a definite shape to the concrete mass, which is carried 5 feet above the tops of the tubes. The space between the planking and the sides of the trench is filled with clay, and the top of the whole is covered with stones. Fig. 222 is a section of the filled trench with tubes in position.

As soon as the concrete has been hardened into a huge monolith, pumps are set to work to empty the tubes. The wooden bulkheads at the adjacent ends of A and B are broken down, and A is put into connection internally with the shore section, the outer bulkhead of A forming the end of the tunnel for the time being. Further sections are added in a precisely similar manner.

The steelwork of the tubes is but the shell of the tunnel. Inside it the concreting gangs form concrete linings 2 feet thick in the top half, and thickened out into square-cornered benches (see Fig. 222) in

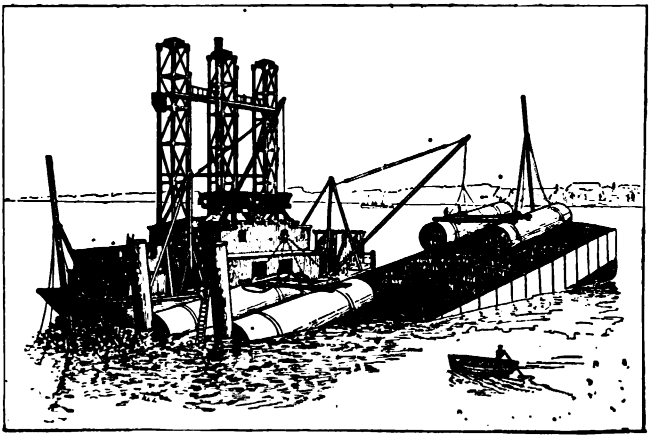


Fig. 223.—

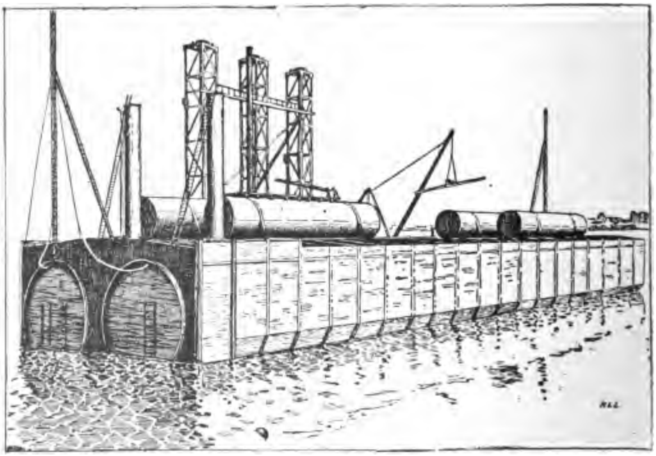


Fig. 224.—The section half submerged.

(From photos, in "Cassier's Magazine.")

the lower half to afford footways for the railway men and for passengers in case of an accident. The clearance between the rails and the centre of the arch is 18 feet.

The tunnel has a total length from portal to portal of 7,960 feet, made up of 2,600 feet of steel sub-river tubing, and 5,360 feet of land tunnel. If the approaches to the tunnels be added, the total length of the works is 12,000 feet, or nearly 2½ miles.

For the land portions of the tunnel two shafts were sunk on each bank, one near the river's edge, the second halfway between the first and the portal, so as to enable excavation to proceed at eight points simultaneously under cover of shields. The inland tunnels are lined with concrete, and will be illuminated with electric lamps. The river-edge shafts are to be retained and lined to assist in the ventilation of the tubes. "They will be clean, and well ventilated, and entirely free from the deadly coal gases which fill tunnels operated by steam locomotives. There will be no grim record of death in the Michigan Central Tunnel." *

The gradient on the American side is 2 feet in 100; that on the Canadian side 1½ in 100.

* *Cassier's Magazine*, xxxiii, 349.

It is calculated that the enormous quantities of concrete consumed in this enterprise will require 300,000 barrels of cement, 250,000 tons of screened gravel, and 1,000,000 barrels of sand, the last coming from a point 60 miles distant. When the tunnels and approaches are finished and the electric plant installed, the train-ferry boats that have plied between Detroit and Windsor for so many years will be needed no longer.

Chapter XXI.

MINING AND MINES.

Various types of mines—Shaft sinking—The Kind-Chaudron system —The freezing process adopted for sinking through quicksands —Fitting up the shaft—Hoisting gear—Ventilation—Natural circulation of air—Furnace ventilation—Fan ventilation—Unwatering a mine—By tunnels—By siphons—By ejectors—By buckets—By pumps—Breaking ground—Underhand and overhand stoping—Timbering—The Lake Superior iron-ore mines—Two methods of working them—The Kimberley diamond mines —Coal mining—Laying out a coal mine—Post-and-stall method of getting out coal—Longwall mining—Coal-cutting machinery —Hauling out the coal—Various systems employed—Hoisting the wagons; time-saving devices.

AS civilization depends so largely on the metals and minerals which are extracted from the earth, the profession of the mining engineer is one of ever-increasing importance. We may, therefore, well spare a chapter for a brief review of the various operations which are performed in the hunt for the hidden treasures of the earth.

As prospecting for minerals does not concern us, we must dismiss it with a word. A deposit, seam, or

reef may be found at a point where it "outcrops"—that is, comes to the surface—or it may be discovered only after laborious probing of the earth with diamond and other drills.

Mines are of many kinds. Some take the form of

FIG. 225.—Air-drills at work in the Rand mines.
(*Photo, Ingersoll Sergeant Drill Co.*)

mountains of ore which can be dug away bodily with steam shovels. Others are merely large bodies of mineral in the ground, easily accessible after a layer of "overburden"—useless earth—has been removed. Or, as in the case of the South African gold mines,

ore may exist in thin reefs, more or less vertical; while the majority of coal mines have comparatively horizontal seams, reached either through very deep shafts or through sloping tunnels. Finally, a single mine may have to be worked at different stages in its history by several different methods.

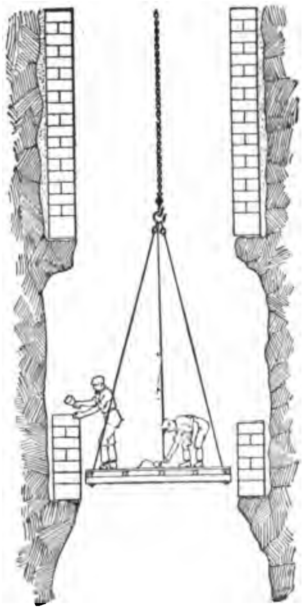


FIG. 226.—Lining a shaft with masonry.

SHAFT SINKING.

A very large proportion of mines are entered through vertical shafts, sunk in some instances to enormous depths. The Red Jacket shaft of the Calumet and Hecla copper mine is nearly a mile deep, and its construction required the removal of 1,500,000 cubic feet of rock. In hard ground, free from water, a shaft is usually of rectangular section, but in the presence of water, or where it has to withstand great pressure, it is cylindrical. The lining is of wood, masonry, or iron plates—most commonly the second. In Fig.

226 we see masons at work. The shaft is sunk and lined a section at a time, a ledge being left at the bottom of each lowest section to support it while it is built up to join the section above. The intervening ledge is broken away piecemeal to allow the masonry to be bonded together. A suspended platform carries the masons, and is raised as the work proceeds.

In water-bearing strata special methods must be adopted. To moderate depths the pneumatic caisson may be sunk in the manner described in connection with the shafts of the Rotherhithe Tunnel. For depths at which the requisite air-pressure would be greater than men could endure, a huge boring tool is used to make a "pilot" shaft 4 or 5 feet in diameter, which serves to guide a somewhat similar but much larger tool that drills out the shaft to full size.

The sinking completed, the lining of circular flanged iron rings, bolted together by the flanges, is lowered. As the bore is quite smooth from top to bottom the lining would become unmanageably heavy when a considerable number of rings had been assembled, unless the engineers pressed the water which has compelled them to adopt the Kind-Chaudron process—as it is called—into their service.

The lowermost rings are provided with a "moss box" which prevents water passing between the lining and the sides of the bore. Near the bottom the lining is spanned inside by a watertight diaphragm, from the centre of which a tube leads to the surface.

This arrangement converts the lining into a gigantic piston or plunger, which can sink down the shaft only if the water below the diaphragm is allowed to escape through the central tube, so that the engineers have complete control over the weight. When the bottom has been reached the space between the lining and the ground is filled in with liquid hydraulic cement, and the water is pumped out. *The freezing process* is employed for sinking through very unstable strata, such as quicksands, in the following manner. A number of bore holes are marked off in a circle sur-

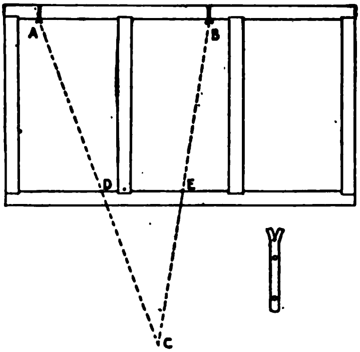


FIG. 227.—Diagram to explain how a point C is transferred from the surface into the workings of a mine. Four guides are fixed at the top of the shaft at A B D E, on lines which meet at C. Plumb-bobs hung from the guides to the bottom make it easy to find a point vertically below C.

rounding the site of the shaft, sunk to a depth at which solid ground is reached, and lined with iron tubes. These tubes then have lead plugs forced down to the bottom to keep water out, and into them are introduced much smaller tubes with open lower ends. A freezing mixture pumped down the inner tubes returns between them and their respective outside tubes to the surface, where it is again cooled to a very low temperature. In the course of a few months the earth, sand, etc., for a considerable distance round the tubes is frozen solid, and is kept in that state while the shaft is excavated and lined in the manner usual for firm ground. One of the most remarkable instances of the successful application of this process is that of a colliery shaft sunk 484 feet through a quicksand. In the shaft bottom the frozen sand was so hard that blasting had to be continued through the deposit. The temperature was here 14 degrees below zero, Centigrade. To thaw the frozen ground warm brine is circulated through the pipes.

FITTING UP THE SHAFT.

The shaft, whatever be its section, is, if a working shaft, divided vertically into several compartments by continuous bulkheads, usually of timber. Two at

least, sometimes four, are reserved for hoisting, and fitted with rails to guide the cages as they fly up and down. Another compartment belongs to the ventilation equipment; another accommodates pump rods, water-pipes, electric cables, etc.

At the shaft bottom are situated offices, pumping stations, and machinery for compressing air and haul-

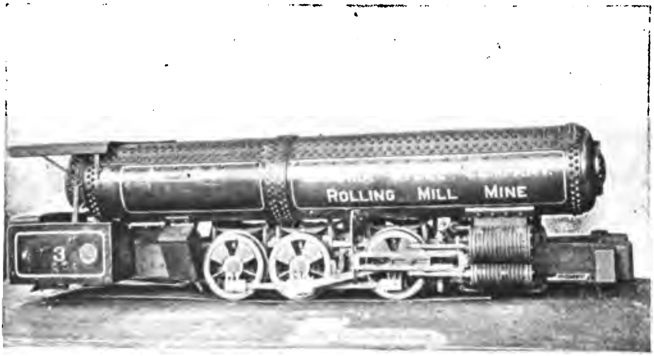


FIG. 228.—Compressed-air locomotive for use in mines.
(*Photo, Baldwin Loco. Co.*)

age purposes. In a coal mine the coal is left untouched for a considerable distance round the bottom —the "pit's eye," the miners call it—so that no injury may be caused by a settlement to this most vital part of the workings.

HOISTING GEAR.

The slow and steady progress of an ordinary pas-

senger lift would be far too slow for mining work. It may come as a surprise to the reader to learn that in some very deep shafts the cages move at the rate of 35 miles an hour—a fair train speed—while 20 miles an hour is quite common practice. The individual loads raised scale many tons, and to rush them up "to bank" requires enormously powerful engines and very strong overhead gear and ropes. The overhead gear, just mentioned, is a prominent feature of a mine, with its towering trestle and pair of huge rope wheels revolving in opposite directions, as one cage rises and the other sinks. The ropes, wound off from and on to huge drums in the engine shed, are generally made of many steel wires twisted together, and in some cases increase in thickness towards the upper end, as the fully unwound rope has to sustain its own weight as well as that of the cage and its load. Where very long ropes are used they form the larger part of the total weight to be raised by the engines.

VENTILATION.

Most mines are provided with at least two shafts, to give a good circulation to the workings. A shaft through which air descends is named a "downcast;" one in which it rises, an "upcast."

Natural circulation is created if the two shafts have their upper ends at different levels, as in Fig 229. In summer, when the outside atmosphere is warmer than the air in the mine, B would be the "upcast," and A the "downcast," because the cold column of air in A is heavier than the shorter column in B. In winter, when air is warmer below ground than above, the buoyancy of the air in A would overcome that of the air in B, and the respective functions of the two shafts would be reversed.

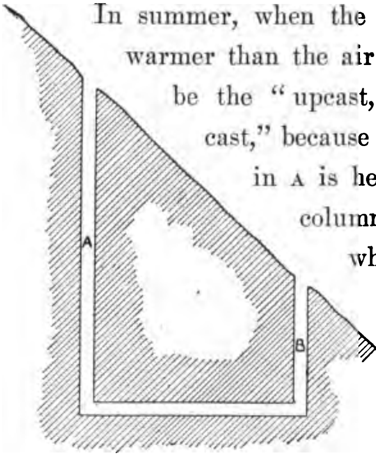


FIG. 229.—System of natural ventilation.

Natural ventilation is erratic, however, and not to be depended on. In coal mines, where fuel is at hand in plenty, furnace ventilation is found convenient. A furnace chamber (Fig.

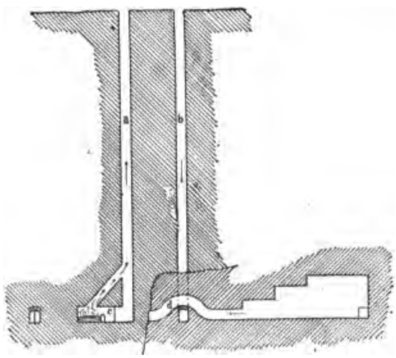


FIG. 230.—Ventilation by furnace draught.

230, *c*) is made near the foot of the "upcast," *a*, to which it is connected by a short inclined shaft. The hot gases rise through this to the surface, and fresh air rushes to the furnace to take their place, after circulating from the "downcast," *b*, through the mine. In Fig. 231 *d d d d* are "cross-overs," the purpose of which is obvious. The arrows indicate the direction of the air currents. A "blind" heading or gallery, *e*, is ventilated by erecting a central partition of cloth, wood, or brickwork almost to the end, so as to compel the air to penetrate it on its way to the furnace.

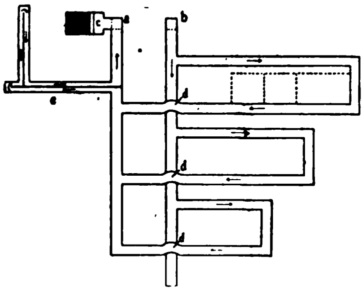


FIG. 231.—Plan of air circulation system in mine.

The ventilation of a coal mine with its hundreds of passages is a somewhat complicated matter. Fig. 232 illustrates the system of building permanent stopings (A A) in those passages which are no longer in use, and fitting double doors (B B) in those along which men and trucks have to pass to divert the air in the desired direction. The double doors form air-locks, one door always being shut, and are so arranged that a truck opens and closes them automatically.

Fan ventilation is now the favorite practice with mining engineers. A huge fan, either belt-driven or coupled up direct to a turbine, is erected in a chamber at the top of one of the shafts (Fig. 233), through which it sucks or drives vast quantities of air.

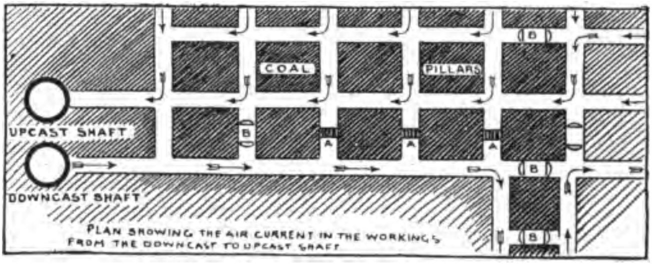


Fig. 232.—Ventilation of a coal-mine. A A A are "stopings" to guide air in the required direction; B B are double doors for communication.

In a well-ordered mine a plentiful supply of air is taken to the remotest corners in which men are at work, even though they be miles from the shafts. The current keeps the miners in good health, and

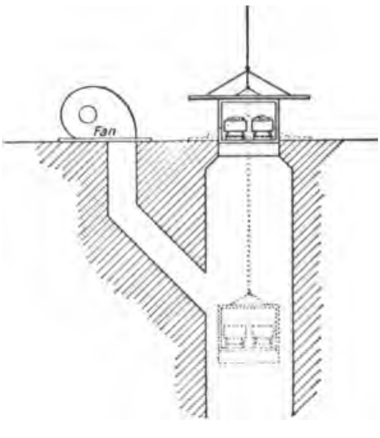


Fig. 233.—Ventilation by fan. A fan placed in a chamber connected with the upcast sucks the foul air out of the workings.

also removes what might be dangerous accumulations of foul and explosive gases; the last being met with most frequently in coal mines.

UNWATERING A MINE.

Freeing a mine of water is one of the most troublesome problems that mining engineers have to solve. In some mines the weight of water removed far exceeds that of the mineral or ore—for example, in the Westphalian coalfield about 3 tons of water are lifted out to every ton of coal; and in Staffordshire the proportion has even reached 28 tons of water per ton of coal. Wherever possible, natural drainage by gravitation is used. A tunnel is driven on a gentle incline through the side of the hill into the bottom of the workings, so as to tap the water at a low level. Even when the mine is sunk below the tunnel, the latter is valuable, as water has to be lifted through a comparatively small height for discharge.

Some wonderful drainage tunnels are in existence, the most famous of them the Sutro Tunnel, driven through 4 miles of rock into the great Comstock Silver Lode, Nevada, at a cost of over $7,000,000. In the Claustal Mines in the Harz Mountains is a 10-mile tunnel; at Freiburg one of 8 miles; and at

Schemnitz the Emperor Joseph Adit burrows for 9 miles. All these are far exceeded by the Great County Adit in Cornwall, which, with its various branches, totals 30 miles. In Wales a drainage adit pours out 15,000,000 gallons by gravitation every twenty-four hours.

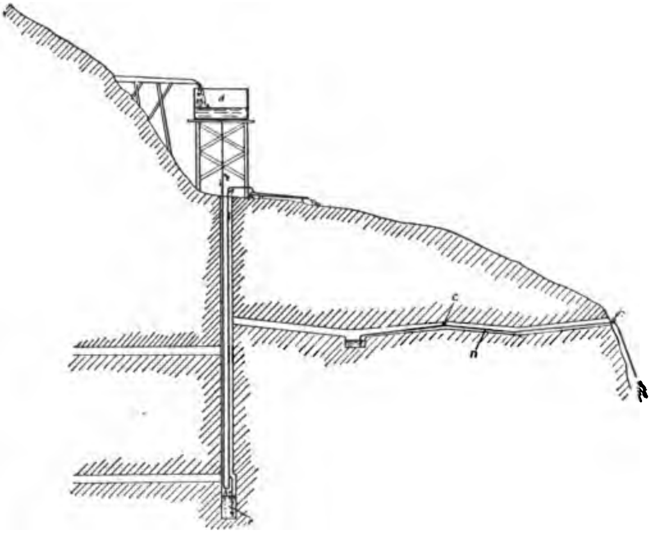


FIG. 234.—Diagram to show siphon and ejector systems of unwatering a mine.

If the tunnel rises towards the entrance or changes level, as in Fig. 234, a siphon pipe is used. The principle is explained in detail by Fig. 235, wherein *a* is the suction pipe and *b* the delivery pipe. A small tank, *c*, is fitted with a footvalve, which opens

upwards, to allow air to escape from the pipe while it is being charged. One of these valves is fixed at the highest point in the siphon wherever the pipe takes a downward course. (See Fig. 234.)

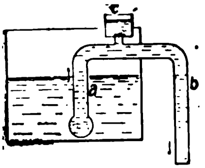


FIG. 235.—Siphon with foot-valve to allow air to escape when the siphon is charged.

In Fig. 236 is illustrated another drainage method, by a *water ejector*. (See also Fig. 234.) A pipe, *e,* leads from a tank, *d,* over the shaft-head down to near the sump *r* at the bottom, where it turns upwards and is continued as a rising main, *f,* to discharge at the surface. A short branch pipe, *h,* dips into the sump, and has at the point of junction a nozzle, *i,* pointing upwards inside pipe *f.* The upward velocity of water through *f* past the nozzle draws water from the sump by suction and carries it, as well as the water from the tank *d,* to the surface.

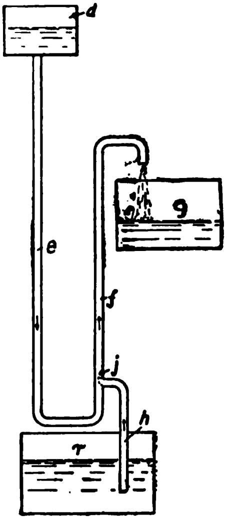


FIG. 236.—A water ejector.

Another method is to lower a large cylindrical bucket by a winding gear into the sump, and draw

it up when it has filled itself through a valve, *k*, which opens when the bucket rests on the bottom of the sump (Fig. 237).

Finally, there is the ejection of water by large pumps stationed at the bottom of the shaft, and operated either by electric motors, fed with current from a power-house above ground, or by long rods working up and down in guides in the shaft.

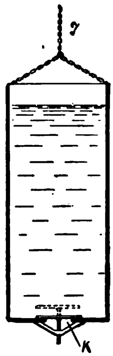


FIG. 237.—Self-filling bucket for lifting water from a mine.

BREAKING GROUND.

We may now proceed to a short description of the getting out of minerals.

Fig. 238 serves to explain some of the most common mining terms. The solid black portions B B indicate seams or veins of the paying material mined for; A A the enclosing rock and clay. A *shaft*, C C C, is sunk through A A, clear of the vein if possible, and from it, at regular intervals, levels, galleries, or drifts, D D, D F, are cut horizontally to and through the vein. Vertical passages, E, called winzes, connect the levels, and so divide the veins into rectangular blocks, named *stopes*. The cutting away of these blocks is called *stoping*. There are two methods of stoping, the "overhand" and "underhand."

Overhand stoping is seen in progress at K. The miners begin operations at the bottom of a stope near a winze, and hack at the roof. The stuff broken away gives them a foothold that rises with the roof. Eventually all the paying stuff is dropped through "rises," or openings in the pile, into trucks in the gallery beneath.

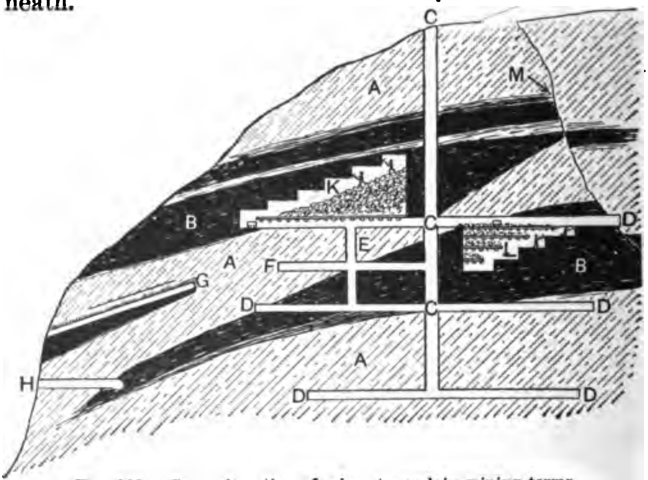


FIG. 238.—General section of mine, to explain mining terms.

Underhand stoping, shown at L, is the reverse process. The miners attack the stope at the top and work downwards, throwing the ore, etc., on to platforms of "stull-pieces," from which it is raised in buckets to the level above, or thrown down through a shoot into wagons below.

Rubbish is separated from paying stuff and used to fill in the stopes with as they are worked out. In some cases it is necessary to bring down filling materials from the surface.

Where a very large mass of ore is encountered, the

FIG. 239.—Timbering in a mine gallery.

gradually rising roof is held up by an elaborate system of timber-framing rising tier upon tier. In the Comstock mines one chamber was 400 feet from floor to dome, and whole forests were felled to supply the timber needed for the work.

The galleries of a mine are timbered (see Fig. 239), and in places even lined with masonry. To drive them, blasting is used as in ordinary tunnelling. The power-drill, which does the work of a score of hand-drills (a bar struck with sledge-hammer, and partly

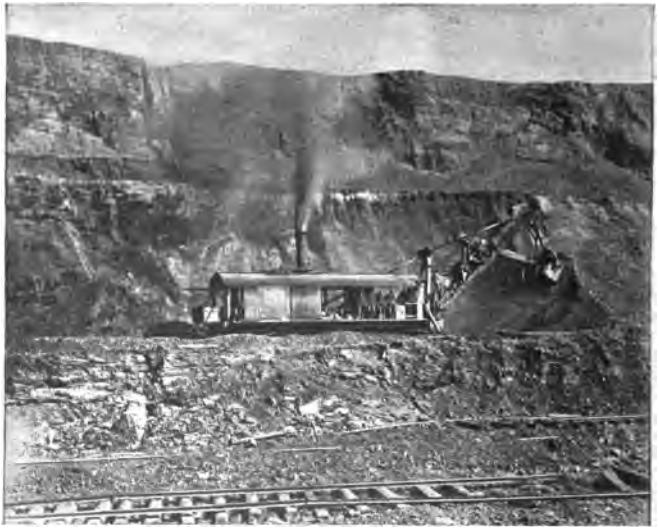


FIG. 240.—A Lucyrus steam-shovel at work moving iron ore.

revolved between every two blows), effects most of the boring in many mines, and greatly reduces the wages bill.

THE LAKE SUPERIOR IRON-ORE MINES.

Within a hundred miles of Lake Superior lie the

great iron-ore deposits of North America. The Gogebic, Vermilion and Mesabi ranges of hills in this district contain hundreds of millions of tons of ore. At many points the ore is scooped out into trucks by great steam-shovels (see Fig. 240), which will load 800 to 1,000 trucks an hour for weeks together. Elsewhere the deposits are worked vertically by several methods, two of which are shown in Figs. 241 and 242. Take Fig. 241 first. A shaft is sunk through the adjacent rock, and a cross-cut is driven into the ore. On both sides of this branch out galleries, Y Y (see the plan). Small shafts, or shoots, X X, are then sunk into these galleries, and down them the miners throw the ore into trucks, which carry it away and dump it into large buckets plying in the shaft. Before the first level is reached, another cross-cut and its galleries and shoots have been made ready for the removal of another layer; and the process is repeated until the deposit has been worked out.

Should the overburden be too thick to be removed profitably another system is adopted (Fig. 242). Two levels are driven, the uppermost immediately below the overburden, and connected by shoots, S S. Level No. 1 is widened out and lengthened, all the ore being

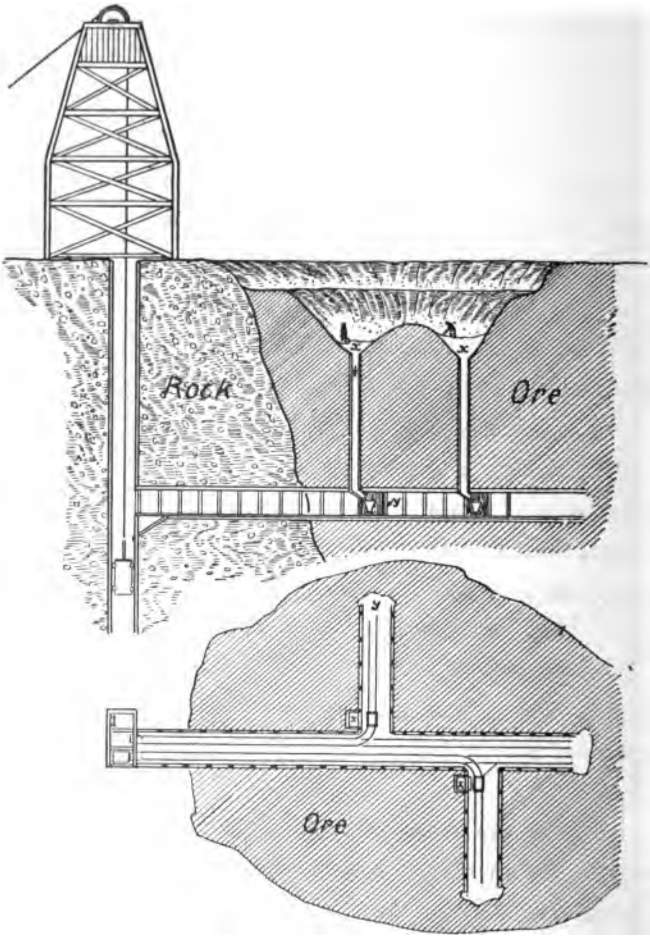


Fig. 241.—Elevation and plan of a method of mining used in the iron-ore mines, Lake Superior region.
(From an illustration in "Cassier's Magazine.")

shot down to the level below, whence it is transported to the shaft. When the ore of the slice has been

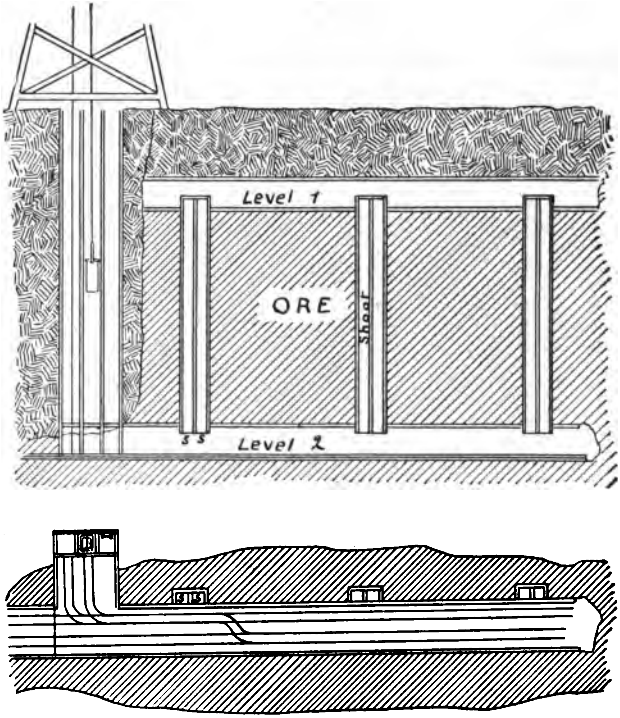


Fig. 242.—Another method of mining iron ore.
(From an illustration in "Cassier's Magazine.")

removed in this manner, the props supporting the earth are blasted away, and the roof allowed to fall in on the floor. Another level is then driven immediately

below No. 1, the floor of which serves as the new roof, and a second slice is excavated. In this way the whole block down to Level 2 is removed, and it then becomes necessary to drive Level 3 and put up fresh shoots to Level 2 before operations can be continued.

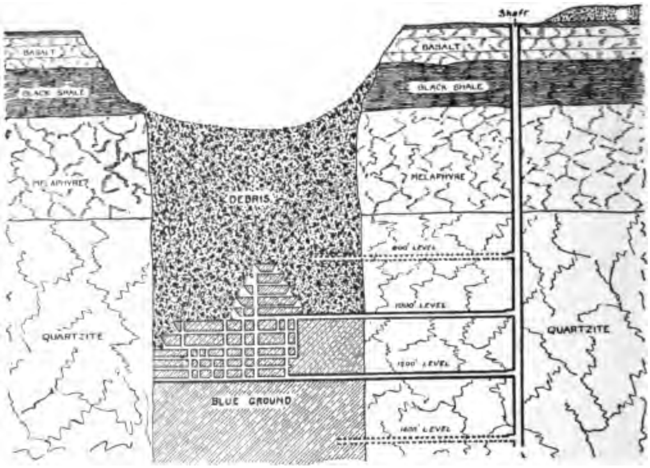


FIG. 243.—Section of a diamond mine. After some of the "blue-ground" has been excavated from the surface a shaft is sunk and the deposit attacked from below.

This method has the advantage of keeping the weight on the roof—that is, the weight of the overburden—constant. It is applied, in a modified form, to the Kimberley diamond mines, South Africa (Fig. 243). These mines were worked at first as "opencast;" but when the depth became too great for con-

venience a shaft was sunk, and the diamond-bearing "blue-ground" (a species of rock) attacked from below, the rubbish being allowed to remain in the "pipe" as an increasing overburden.

COAL MINING.

The extraction of coal from the seams in which it has formed during the course of ages is the most important of all mining industries. In the year 1907 the total quantity of coal raised in the United States, Great Britain, Germany, France, and Belgium exceeded 800,000,000 tons. Of this about one-half was mined in the United States, where the annual consumption of the mineral averages 4½ tons per head of the population. The United Kingdom requires about 4 tons per head.

Coal occurs in seams from a few inches to 100 feet in thickness, and as a consequence coal-mining practice includes several different methods of "winning" the material. In Great Britain the vast majority of coal mines are worked through vertical shafts, sunk in some instances to depths exceeding 2,500 feet, from which passages are driven through the coal on a systematic plan. In the United States, especially in the "soft" or bituminous coal regions, a great deal

of the mineral is won through horizontal or inclined tunnels (see H and G in Fig. 238), and through "slopes," which are shafts dipping at a considerable angle to the vertical.

LAYING OUT A COAL MINE.

There are two main methods of removing the coal. The first of these consists of cutting parallel galleries in directions at right angles to one another, so as to divide the seam into a number of rectangular blocks, which correspond in a horizontal plane to the vertical "stopes" of an ore vein. These blocks, known variously as "pillars," "posts," and "banks," are robbed in regular order either from the boundary of the mine towards the shafts, or from the shafts towards the boundary. In the latter case roads for haulage and access have to be left in the "goaf" or "gob," as the rubbish is called with which the excavated chambers are filled (see A in Fig. 244). The system just described is termed the "post and stall," or "pillar and stall" system, the word stall signifying the passages which surround the pillars. In former times part of the pillars was left to hold up the roof, but nowadays the coal is robbed completely.

In thin seams of four feet and less in thickness the

longwall method is more generally employed. A comparatively few passages are driven, and the coal is attacked on long faces, as shown in Fig. 245. As in the first method mentioned, progress may be either outwards or inwards, or in both directions simultane-

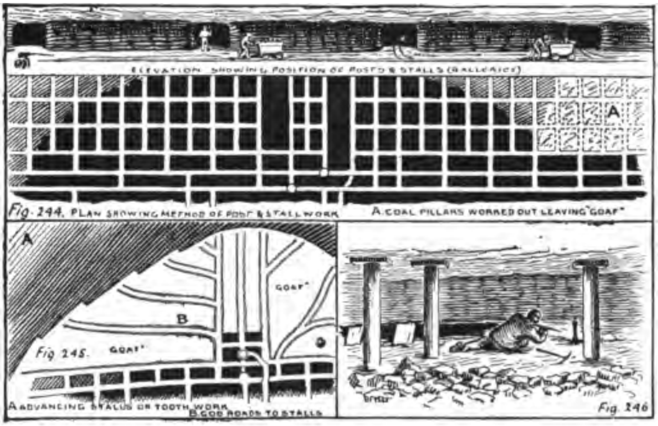


Fig. 244.—Plan of coal-mine worked on the "post and stall" method. The two small circles are shafts.
Fig. 245.—Longwall mining.
Fig. 246.—A longwall miner undercutting the face.

ously in different parts of the mine, to keep the *average* distance of hauling as constant as possible.

The longwall miner undercuts the face to a depth equal to the thickness of the vein, so as to form a groove at the bottom of the seam (Fig. 246). The coal is supported by short wooden sprags, so that the miner may run little risk of being crushed by a fall.

When the length has been "holed," the sprags are knocked out, and if the coal does not fall by its own weight holes are drilled in the top of the seam and it is blasted down.

CUTTING MACHINERY.

For longwalling in soft coal mechanical cutters are

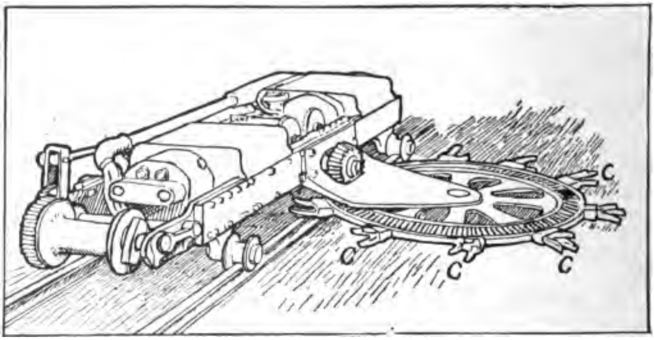


FIG. 247.—A machine for undercutting coal. C C C are cutters attached to the circumference of a wheel revolved by compressed air or electricity.

now widely employed, especially in the United States. These machines are of many types. One resembles a horizontal circular saw (Fig. 247), with cutting chisels set at regular intervals round the circumference of a wheel five feet or more in circumference. Another variety has a long revolving toothed bar, which saws through the coal much like an ordinary saw. There is, too, the machine with a spiked chain

passing round the end of a long arm; and a device which imitates the action of a miner striking with a pick.

These machines travel on rails laid parallel to the face of the coal, and are driven by compressed air or electricity. One machine will do the work of from fifteen to twenty men, and with less waste of coal. Furthermore they relieve the miners from doing extremely hard labor in very cramped attitudes.

HAULING OUT THE COAL.

In shaft mines two main haulage roads are run from end to end of the workings. Each road is equipped with a single or, where the quantities moved are unusually great, with a double rail track. In either case, arrangements are made to keep the full trucks moving towards the shaft on a separate track from that by which the empty trucks return. From the main track side tracks branch out. These are frequently operated by boys who push the trucks up to the main line, where they are coupled up with the haulage ropes.

The ropes are driven by an engine near the pit bottom. A rope passes from one drum to the end of the track, round a large horizontal pulley, and back

to a second drum. The drums turn in opposite directions, and the one takes in the rope as fast as the other pays it out; or an endless rope is kept moving continuously in one direction. Trucks can be hitched to the ropes at any point.

In Fig. 248 we have instances of roads running uphill in the one case (*a*) and downhill in the other (*b*). In *a* it is necessary to use a tail rope passing round pulley *c* to draw the empties back to the working, unless the haulage be so arranged that the full cars running down pull the empty cars back on a separate track.

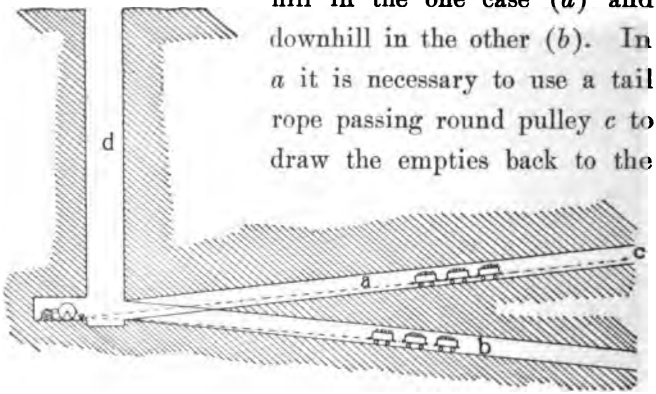


FIG. 248.—Hauling wagons to the foot of a shaft.

On a downhill track the cars return to the working by gravity, and power is needed only to bring them to the shaft.

In Fig. 249 we see the method of operating a side road, *f*, in combination with the main road. To draw

trucks from the branch, the main road ropes are uncoupled at *e e* and hitched on to those in *f*. Any number of branch roads can be worked in this way.

In mines entered through a horizontal tunnel, haulage locomotives are often found very useful and convenient. These locomotives are propelled either by compressed air stored in a large boiler-like cylinder (Fig. 228) or by electric current picked up by a trolley arm from

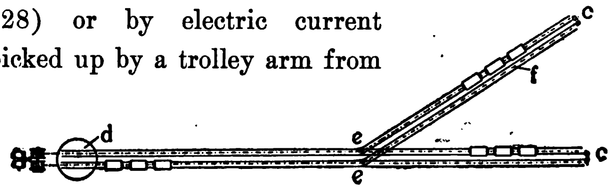


Fig. 249.—Diagram to explain how a branch track is worked in combination with the main track in mine galleries.

an overhead cable. An illustration is given (Fig. 250) of an electric locomotive emerging from a mine with its train of trucks.

We may conclude this chapter with a notice of the manner in which skips are put on board hoisting cages and removed from them with the least possible delay. The lift has several stories for as many tiers of trucks. At the pit bottom there is a hydraulic lift with floors to correspond with those of the cage. The lift is lowered, and a few trucks are shoved on board. It rises till the second floor is on a level with the rails and receives a second batch, and so on till

it has its full load. When the cage descends the empty trucks are discharged into a second lift, which transfers them in batches to the rails, and the full trucks are pushed in, all tiers simultaneously. At the top

FIG. 250.—An electric locomotive hauling a train of trucks from a mine adit.

of the shaft is a similar installation, which clears the cage of full trucks and loads it with empties. Thus no time is wasted, as the lifts are being filled and cleared while the cage is travelling in the shaft.

[*Note.*—Any reader who is specially interested in mining should consult "The Romance of Mining," in which are given full accounts of many of the world's greatest mines, and a more detailed description of their working than could be included in this chapter.]

Chapter XXII.

POWER FROM FALLING WATER.

The pressure of water—The wasted energy of Niagara Falls—Early attempts to use it—Great development—An industrial Niagara —Great installations—Facts about power companies at Niagara —Method of generating power—The Ontario Power Co.—Huge water-pipes—A relief weir—Types of turbines—A monster turbine—Future development of water power—High-pressure water power.

IN many towns the pressure of the water supply is such that if you press your thumb against the nozzle of a house tap and open the valve the water will force its way out in angry spurts. Whence comes this power? From the weight of the water. If the surface of the reservoir which feeds the main be 100 feet higher than the tap, your thumb has to support a column of water 100 feet high, having a section equal to the area of the hole in the nozzle, and weighing about 45 lbs. to the square inch. Were the tap-water directed into a turbine of suitable size, it would generate sufficient energy to light several electric lamps.

The amount of water that issues from a tap is very

trifling as compared with that which passes over many a waterfall. At Niagara a solid wall of water, 20 feet deep, representing 275,000 cubic feet per second, thunders 200 feet into the abyss. Expressed in terms of energy, Niagara Falls develop 7½ million continuous horse-power—more in a year than that which would be produced were all the anthracite coal mined annually in the United States consumed in the furnaces of steam boilers.

For centuries this prodigious energy has been expending itself in carving a deep, narrow channel through the rock that separates Lakes Erie and Ontario. Man first feared the magnificent waterfall; then he admired it; and now, in an age when the useful often has to take precedence of the beautiful, he seeks to force some of this natural power to serve his ever-increasing needs.

As long ago as 1725 a saw-mill wheel—a crude and imperfect contrivance—was set up at the edge of the Falls. The growth of the steam engine in the early half of the nineteenth century retarded the development of an industrial Niagara, and not until 1870 was the problem of utilizing the Falls' inexhaustible power seriously attacked. In 1886 a syndicate

secured from the New York Legislature a concession to take sufficient water from the upper river to develop

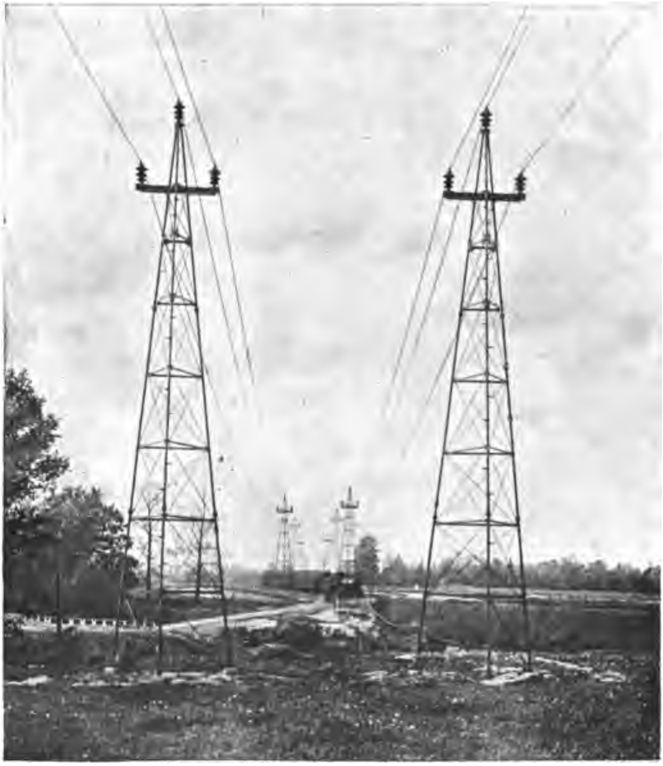


FIG. 251.—View of power-transmission lines.
(*Photo, Ontario Power Co.*)

200,000 horse-power. People wondered what use could be found for even a tenth part of this. The

syndicate went ahead. To-day 400,000 electrical horse-power is generated by turbines within a few hundred yards of the Falls, and provision has been made for installations which will in time raise the total to 900,000 horse-power.

The result is seen in the growth of a great manufacturing city on the American side of Niagara, in which not a single steam-engine pants, though coal is very cheap in the locality. Even in Buffalo, where coal costs only $1.50 a ton, electric power, transmitted 23 miles from the Falls, has completely ousted steam; a fact which is not a matter for astonishment, considering that the generating companies supply current at the rate of $25 a year per horse-power running continuously. This works out at about one-third of a cent per hour. It may well be asked, who would do the mere shovelling of coal into a furnace for this money? Every year the great electrical tentacles reach out further and further, and grip town after town. Already the street cars of Syracuse on the east and of Toronto on the west—250 miles apart—are operated by Niagara power, as is also a section of the Erie Railroad, 150 miles distant. Within a few years towns 300 miles away will be tapping the energy of the great Falls.

FACTS ABOUT THE POWER-HOUSES.

The chief installations running at Niagara are:—

On the American Side.

1. The Niagara Falls Power Co., with two power-houses developing 105,000 h.p.

2. The Niagara Falls Hydraulic Power and Manufacturing Co.; 65,000 h.p.

On the Canadian Side.

3. The Niagara Falls Canadian Power Co., designed to generate 110,000 h.p. with 11 dynamos.

4. The Electrical Development Co.; 125,00 h.p.

5. The Ontario Power Co., for 180,000 h.p.

Of these Nos. 1 and 3 are owned by the same corporation, and are connected through cables carried across the gorge on one of the bridges that span it.

METHOD OF GENERATING POWER.

The difference in level between the upper river and the rapids below the Falls is about 200 feet. The turbines are in all cases situated 170-180 feet below the surface of the upper river, and the water is supplied to them through penstocks, or vertical pipes,

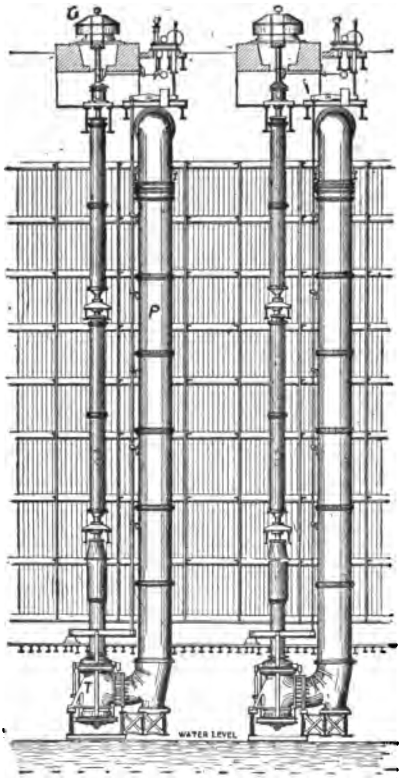


FIG. 252.—A wheel-pit in the Niagara Falls Power Co.'s installation. G = generator; S = shaft; T = turbine; P = penstock. The pit is 178 feet deep.
(*From an illustration in "Cassier's Magazine."*)

the largest of which are 11 feet in diameter. The installations 1, 3, and 4 have deep wheel-pits cut in the rock *above* the Falls for the penstocks and turbines, the latter revolving long shafts which carry the moving parts of generators stationed in power-houses on the surface of the ground (Fig. 252). To get rid of the water when it has passed through the turbines, tunnels have been driven through the rock on a gentle gradient to points below the Falls. The tunnel, or "tail-race," of the Niagara Falls Power Co. is 7,000 feet long, with a maximum sec-

tion of 21 feet by 18 feet 10 inches. The driving of this tunnel occupied 1,000 men continuously for three years; required the removal of 300,000 tons of rock; and consumed 16,000,000 bricks for its lining. Add the quarrying out of 123,455 cubic yards of rock for the wheel-pits, and you realize that here a very considerable engineering feat has been performed.

The method preferred for in-

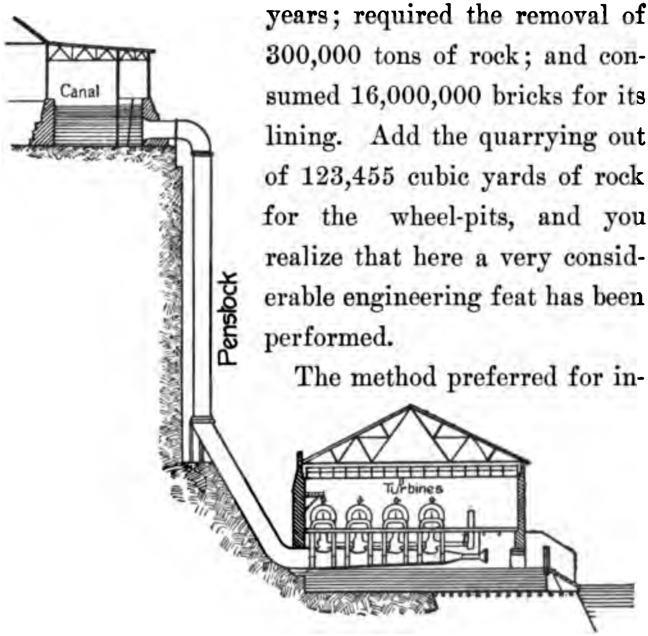


Fig. 253.—Diagram of power-house of the Niagara Falls Hydraulic Power and Manufacturing Co., showing penstocks carried down the cliff from the canal to the turbines.

stallations 2 and 5 was to build the power-houses *below* the Falls, and to lead water through great covered pipes, or through canals in the banks of the upper river to penstocks affixed to the face of the cliffs. Fig. 253 is a sketch of the penstocks and power-house of

FIG. 254.—Laying an 18-foot flume in Victoria Park, Niagara Falls.

FIG. 255.—The flume partly encased in concrete before the trench is filled in.
(*Photos, The Ontario Power Co.*)

the Niagara Falls Hydraulic Power and Manufacturing Co. This system obviates the need for a costly tunnel and deep wheel-pits. All the work done is surface work.

By the courtesy of the Ontario Power Co., I am enabled to give illustrations of the process of laying one of the three great 18-foot steel flume pipes which will ultimately supply their power-house. About a mile above the Falls a great wall about 600 feet long has been built out obliquely into the river, slanting down stream. Nine feet below the water level it is pierced by a number of sluices, controlled by gates, through which water enters the *forebay*. From the end of the intake wall a submerged spillway slants away to the shore; so that a triangular area is enclosed by the shore, the intake, and the spillway. As the intake makes a very acute angle with the general direction of the current, it affords no lodgement for the ice which floats down plentifully in winter and early spring.

From the main forebay the water passes into an inner forebay, excavated in the bank, through a second intake also provided with deep-level sluices, and so reaches the gate-house, where are entrances to the three flumes, one of which is completed. Any ice

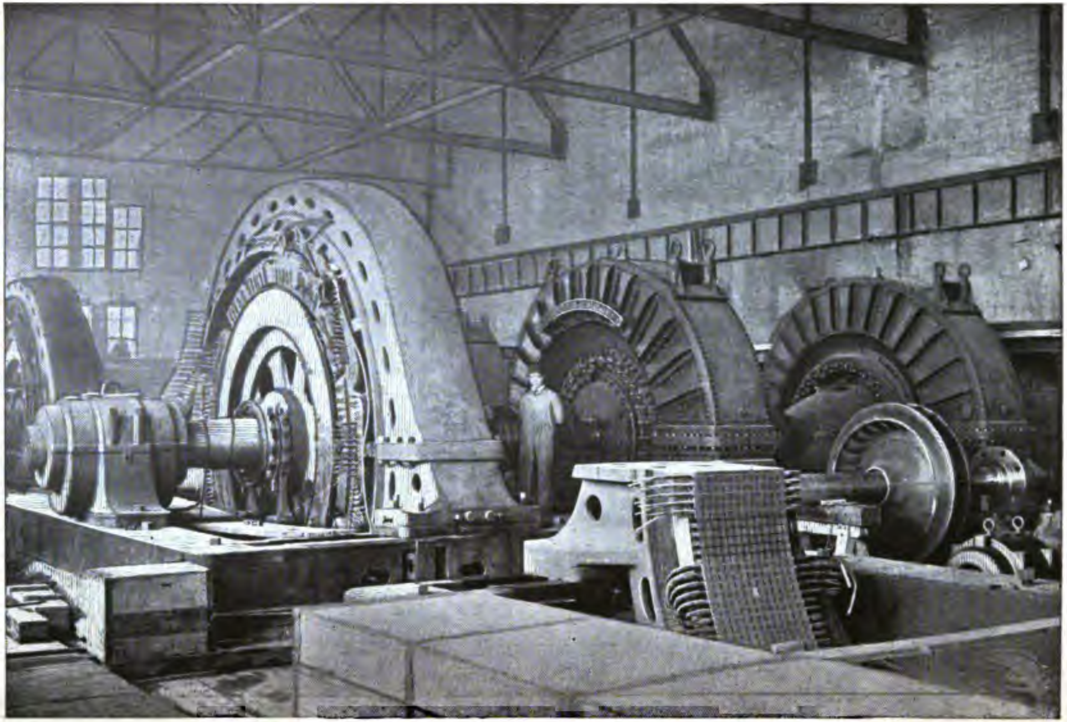


FIG. 256.—One of the 10,000 h.p. units in the power-house of the Ontario Power Co. Generator on left; twin turbines on right.
(*Photo, The Ontario Power Co.*)

that may have penetrated to the inner forebay is kept out by wide-mesh screens.

The flume, 18 feet in diameter and 6,500 feet long, is laid in a deep trench and covered over with concrete and earth, so as not to disfigure the scenery of the Victoria Park, through which it passes. Arriving at the cliff below the Falls, it throws out on the under side six 9-foot penstocks (see Fig. 257), carried down in pairs through vertical shafts and horizontal tunnels cut in the solid rock to the turbines of the generating station, built on a ledge 20 feet above the level of the lower river. The turbines are mounted horizontally in pairs on the same shaft as a single generator which, at 187½ revolutions a minute, has an output of 11,400 electrical horse-power. Fig. 256 shows one of the twenty "units" with which the power-house will be equipped ultimately. The man seen between the generator and a turbine affords a standard by which to judge the dimensions of the machinery.

The current generated is taken through cables laid in inclined tunnels cut in the cliff up to a large distributing station built on an elevation 250 feet above the turbines. An interesting feature of the hydraulic engineering needed for the work is the *relief weir* (see Fig. 257) at the penstock end of the flumes. To

prevent an undue strain on the flume when a penstock valve is closed, the water is allowed to rise up an inclined orifice and fall over a weir into a drain that

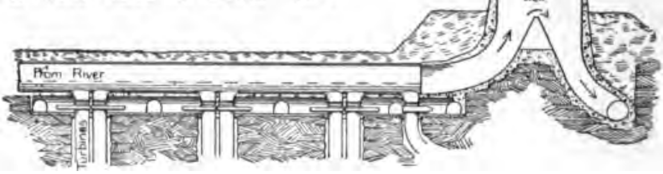


FIG. 257.—Section of relief weir at end of flume. When a penstock valve is closed, undue pressure is prevented by the water rising over the weir. (*Photo, The Ontario Power Co.*)

leads it away to the river. As soon as the temporary pressure is relieved the water subsides behind the weir to its normal level.

TYPES OF TURBINES.

Water turbines are of two main types: (a) *Axial flow* turbines; (b) *radial flow* turbines.

An axial flow turbine resembles in principle the ordinary windmill. The water travels in the direction of the axis of the shaft, and moves sideways the vanes attached at right angles to the shaft. In radial flow turbines the water moves towards or away from the shaft through vanes set in rings attached to the shaft. In all cases fixed guides are used to make the water strike the moving vanes at an effective angle.

The Niagara installations have axial flow turbines. In the Niagara Falls Power Company plant, where the turbines are at the bottom of a deep pit, they are so designed that the upward pressure of the water in each turbine shall support the thirty-five tons weight of the shaft and revolving portion of the generator. The water passes from the penstock into a barrel-shaped chamber, and spurts out through rows of guide blades set around the circumference at the top and bottom. Immediately outside the barrel, opposite the guides, are vanes attached to two rings. The

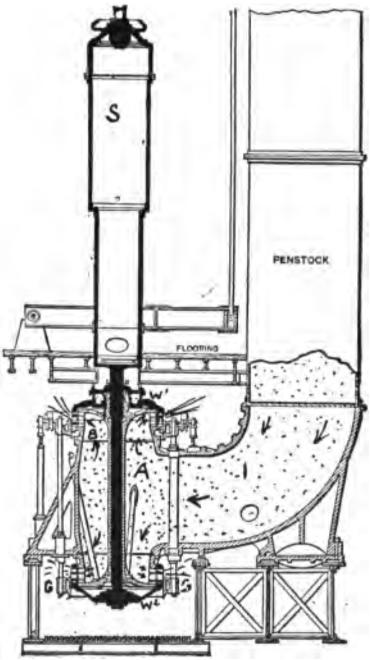


FIG. 258.—Section of one of the turbines in the Niagara Falls Power Co.'s installation. The revolving parts are marked in solid black. A = body of turbine; B = fixed guides; W^1 W^2 = rings carrying moving vanes; G G = governor regulating the amount of water passed through the vanes; S = shaft.

water strikes these at an angle and causes the rings to revolve. These rings turn a shaft which penetrates both ends of the barrel. The top end of the barrel is pierced with holes, so that the water may press upwards against the under side of the upper ring and support the shaft and its load. As the gland in the bottom of the barrel, through which the shaft passes, is water-tight, there is no downward pressure to counteract the upward thrust on the top ring. (See Fig. 258.)

The Ontario Power Company, in common with two other of the big installations, employs turbines of the "Francis" type. The water enters a chamber surrounding the wheel, passes through guides, and strikes the moving vanes squarely. It is then deflected so as to leave the turbine in the line of the shaft. This type is best suited for driving generators mounted on horizontal shafts.

The largest single water turbine in existence is that installed at the Shawinigan Falls on the St. Maurice River, a tributary of the river St. Lawrence. The makers of this gigantic wheel, the I. P. Morris Company of Philadelphia, have kindly furnished me with a fine illustration (Fig. 259), which will give the reader some notion of its size. It has a capacity of

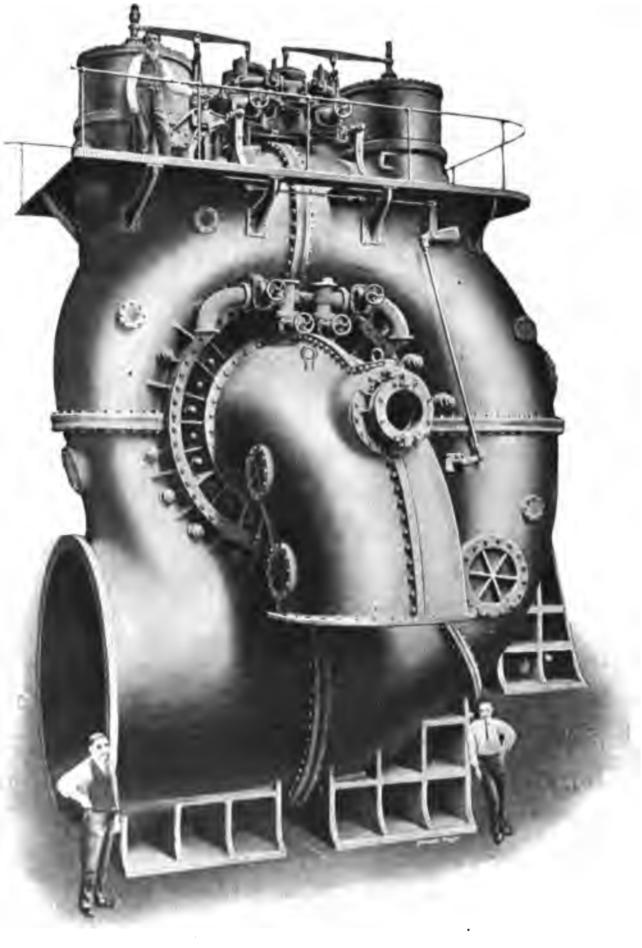


Fig. 259.—The largest water-turbine in the world, installed at the Shawingian Falls power-house. It develops 10,500 h.p. Weight, 180 tons; height, 30 feet; width, 22 feet. In one minute 400,000 gallons of water flow through it. Made by the I. P. Morris Co., Philadelphia.

10,500 horse-power. It measures 30 feet from base to top, is 22 feet from back to front, and 27 feet wide between the bearings of the shaft. Its total weight is about 180 tons, 10 tons being accounted for by the shaft, a giant bar 22 inches in diameter. The rotatory part of the turbine is a 5-ton bronze casting. In one minute 400,000 gallons of water pass through the turbine when it is under full load. This quantity would suffice to form a river 100 feet wide and 5 feet deep, flowing at a rate of about 1⅓ miles an hour.

Progress in electrical science and the design of economical hydraulic engines seriously threaten the supremacy of steam as a motive power. In all civilized countries where there are waterfalls or mountain streams of large volume, the engineer is devoting his attention more and more closely to the work of harnessing the enormous forces of falling water. In many parts of the United States, Canada, Japan, Norway, Sweden, Switzerland, Italy, France, Germany, Austria, and even in the United Kingdom, new water-power plants are being erected every month. We are as yet but on the edge of a revolution in our methods of capturing energy for locomotion, lighting, heating, and factory operations. Many big rivers are still running free. In due course they too

will contribute their quota of power to the use of man. At the present time a huge project is on foot for utilizing the Victoria Falls on the Zambesi. The Falls have a drop of about 400 feet, and the volume of water passing over them is far greater than that which draws visitors to Niagara. Before many years have elapsed we shall hear of electric current being transmitted from the Zambesi to the gold mines on the Rand, 600 miles away, and of the growth, near the Falls, of great manufacturing towns. The "smoke that thunders," as the natives name the mist rising from the gorge, will never be sullied by coal smoke, because fuel will not be needed for many miles around.

HIGH-PRESSURE WATER POWER.

The Niagara turbines use water that has a pressure at the foot of the penstocks of about 65 pounds to the square inch. At Manitou, Colorado, there is an installation of Pelton water-wheels operated by water falling 2,417 feet, with a pressure of 1,000 pounds to the square inch. The water is collected high up on the mountain side, and descends through pipes to the generating station in the valley, whence, after turning the wheels and expending most of its energy, it passes into the town mains, and so serves a second and no less

useful purpose. So great is the strain on the pipes that ordinary lead joints could not be used, because the water simply squeezed out the soft metal. An alloy of tin and lead had to be substituted. The water issues from the nozzles at a velocity of 204 miles an hour in a bar that cannot be struck through with a heavy iron rod. Such a stream of water cannot be governed by throttling, as the slightest sudden check would wreck the pipes; so to meet variations in the load of the dynamos, the governors of the wheels are arranged to deflect the line of the nozzle below the buckets when less power is needed, and to discharge the water into a long pool. If, for any reason, the valves have to be closed, the operation is performed through a gear which cannot completely cut off the water in less than twenty-five minutes. Even at this slow rate of retardation there is considerable extra pressure set up in the pipes.

[*Note.*—For a full description of the Pelton wheel, see "How it Works," pp. 375, following.]

THE END.